Answers to exercises

Chapter 1

1 *homogeneous*: a, c, d, h; *heterogeneous*: b, e, f, g, i

2 **a** *Mixture*: c; *pure substances*: a, d, h
b All the heterogeneous substances are mixtures.

3 b, d, e, h, i

4 *heterogeneous*: a (if in a glass with bubbles present), c (usually has water droplets dispersed through the gas mixture), f, g. a would be homogeneous in the sealed bottle or if let go flat.

5 compound; because it can be decomposed into two simpler substances, the silvery liquid and the colourless gas.

6 element; it only melted when heated (and solidified again when cooled): it did not decompose into other substances.

7 Blue solid decomposed into black solid plus a colourless gas: the gas is the missing 0.36 g. Compound; because it can be decomposed into two simpler substances.

8 use a sieve; alternatively add water, stir and decant the suspension of aluminium oxide in water: the lead pellets are so heavy that they remain on the bottom.

9 **a** evaporate to dryness
b distil the mixture and collect water as the distillate

10 **a** pure ethanol; it has the lower boiling point and the difference in boiling points is quite large.
b less concentrated in acetic acid (boiling points are too close to get a complete separation)
c chloroform
d use fractional distillation
e pure hexane

11 fractional distillation; difference in boiling points (Table 1.4)

12 Your flow chart should show (a) adding water and stirring to dissolve magnesium sulfate, (b) filtering to separate off the insoluble barium sulfate, (c) drying the barium sulfate, (d) evaporation to dryness to recover the magnesium sulfate.

13 **a** 1 is filtration, 2 is using a separating funnel, 3 distillation, 4 evaporation to dryness.
b X is charcoal, Y is sodium sulfate, Z is kerosene.
d use distillation at 4. For diagrams: Figures 1.3 for (1), 1.7 for (2), 1.5 for (3) and 1.4 for (4)

16 Pass the mixture through a tube cooled to below –33°C; ammonia condenses out but nitrogen and hydrogen gases pass through.

17 Pass the mixture through a tube cooled to 0°C (nitrogen dioxide condenses out) then through a tube cooled to less than –78°C (carbon dioxide condenses out); liquefy the remainder at –196°C (liquid nitrogen temperature) or lower, then fractionally distil the liquid: nitrogen boils off first then carbon monoxide and finally nitric oxide.

18 fractional distillation; difference in boiling points; boiling point increases as volatility decreases

20 Mix bauxite with hot concentrated sodium hydroxide solution, filter off the insoluble iron(III) oxide and dirt, cool the solution; aluminium oxide crystallises out. Filter it off and dry it. (Actually it is aluminium hydroxide that crystallises out: after filtering it off it can be heated to convert it back to oxide.)

21 **a** **i** sulfur, gallium, lead bromide, magnesium, carbon tetrabromide
ii bromine, carbon disulfide, hydrogen peroxide, phosphorus trichloride
b gallium, sulfur, carbon tetrabromide, lead bromide, magnesium
c carbon disulfide, bromine, phosphorus trichloride, hydrogen peroxide
d neon, carbon disulfide, phosphorus trichloride, sulfur dioxide

22 no; did not have a sharp melting point; yes; had a sharp melting point which did not change after further purification; carbon tetrabromide.

23 **a** 2.71 g/mL **b** 1.5 g/mL **c** 7.1 g/mL

24 **a** 4.0 g (3.95 rounded to two significant figures because of 5.0 and 0.79)

b 4.6 g

c 17 g (16.5 rounded to two significant figures because of 0.66)

25 **a** 6.8 mL **b** 23 mL **c** 28 mL

26 0.73%; 7300 ppm

27 49% urea, 22% ammonium phosphate, 29% potassium chloride

28 20.7% ethanol, 47.1% ethylene glycol, 32.1% glycerol

29 *A*, *D*, *E*; they all have significant electrical conductivity

32 **a** There are only five: carbon, phosphorus, sulfur, selenium and iodine. You will get different values in (b)(i) depending upon whether you use red or white phosphorus and rhombic or monoclinic sulfur.

33 **a** There are only eleven possibilities to choose from: oxygen, nitrogen, hydrogen, helium, neon, argon, krypton, xenon, radon, fluorine, chlorine. Those that are gases at −190°C are nitrogen, hydrogen, helium, neon.

Chapter 2

1 **a** more vigorous vibrations

b more vigorous vibrations and more rapid translational motion

2 to increase; stay the same; because the particles are moving more rapidly and so exert greater force (pressure) on the plunger.

3 There is much more empty space in gases than in liquids and the particles move more rapidly and travel longer distances between collisions in gases than in liquids.

4 **a** 2 N atoms and 1 O atom

b 2 O atoms and 1 S atom

5 **a** *In Figure 2.3*: NO, H_2O, CS_2

ii *In Figure 2.4*: H_2O, H_2O_2, CO, CO_2

b **i** PH_3 **ii** N_2O_5

6 **a** 5 **b** 14

7 **a** any three of He, Ne, Ar, Kr, Xe, Rn

b any of H_2, N_2, O_2, Cl_2, F_2 and CO, NO, HF, HCl, HBr, HI

c possibilities include CO_2, NO_2 and H_2S

9 atomic number 11, mass number 23

10 helium: 2, 4, 2, 2, 2
sulfur: 16, 32, 16, 16, 16
oxygen: 8, 16, 8, 8, 8
bromine: 35, 80, 35, 45, 35
boron: 5, 11, 5, 6, 5

11 First number is number of protons and number of electrons; second number is number of neutrons: Sc (21, 24); Ti (22, 26); V (23, 28); Cr (24, 28); Mn (25, 30); Fe (26, 30);

12 for B, O, P, Ar, Ca, see Table 2.4. Mn 2, 8, 13, 2; Se 2, 8, 18, 6; Kr 2, 8, 18, 8; Rb 2, 8, 18, 8, 1

13 **a** Must fill the first level before starting the second; 2, 2.

b Must fill the second before starting the third; 2, 8, 3.

c Cannot have more than 8 electrons in the second level; 2, 8, 3.

d Cannot have more than 8 electrons in the second level, but can have 18 in the third; 2, 8, 18, 2.

14 N 2, 5; Al 2, 8, 3; S 2, 8, 6; Ca 2, 8, 8, 2; N tends to gain 3 electrons, Al tends to lose 3, S tends to gain 2, Ca tends to lose 2.

15 *for Exercise 12*: B 2, 3; O 2, 6; P 2, 8, 5; Ar 2, 8, 8 (no valence electrons); Ca 2, 8, 8, 2; Mn, 8, 13, 2; Se 2, 8, 18, 6; Kr 2, 8, 18, 8 (no valence electrons); Rb 2, 8, 18, 8, 1

16 **a** 2 **b** 4

17 **a** Al, Ga **b** Si, Ge **c** P
They have the same number of valence electrons as the given atoms.

18 **a** 4 **b** 7 **c** 1

d 3. Number of valence electrons equals the Group number.

19 *A* to 2, 8; *B* to 2, 8, 8; *C* to 2, 8; *D* to 2, 8, 18, 8; *E* has no reactions as it is already a stable configuration.

20 **a** K (2, 8, 8, 1) donates one electron to F (2, 7) to form K^+ (2, 8, 8) and F^- (2, 8); KF

b Ca (2, 8, 8, 2) donates one electron to *each* of two Br atoms (2, 8, 18, 7) to form Ca^{2+} (2, 8, 8) and Br^- (2, 8, 18, 8); $CaBr_2$

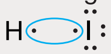
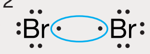
21 **a** Stable ions are K^+ (2, 8, 8) and Br^- (2, 8, 18, 8) so KBr. To form K_2Br would need Br^{2-} (2, 8, 18, 8, 1) which is not a stable configuration; similarly KBr_2 would require K^{2+} (2, 8, 18, 7) which also is not a stable configuration.

22 *positive ions*: Rb, +1; Mg, +2; Ga, +3; K, +1; Ba +2; Cs, +1; *Negative ions*: I, −1; S, −2; Br, −1; Se, −2; F, −1; *No ions*: Si, C, Ar, B, P

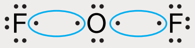
23 **a** **i** Mg, 2, 8, 2; Mg^{2+}, 2, 8

ii S, 2, 8, 6; S^{2-}, 2, 8, 8

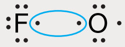
b **i** MgS **iii** $MgCl_2$

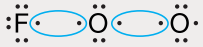
24 **a**  HI **b**  Br_2

25 **a** O (2, 6) needs to gain two electrons; F (2, 7) needs to gain one. To satisfy both drives two F atoms combine with one O atom:



For FO and FO_2 at least one atom would have only 7 electrons and so would not be stable:

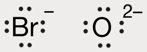




26 **a** SCl_2; S needs to gain 2 electrons, Cl needs to gain 1, so we need two Cls for each S.

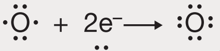
b HI; each atom needs to gain just 1 electron.

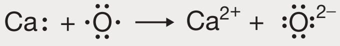
27 **a**



c *Atoms*: Ba: Cs· *Ions*: Ba^{2+} Cs^+

28 **a** **i** $Ca\!: \longrightarrow Ca^{2+} + 2e^-$

ii 

b **i** 

29 PCl_3 is covalent, $CaCl_2$ is ionic.

30 They are ionic compounds whereas the others are covalent.

32 CO_2 exists as small discrete molecules with only weak intermolecular forces between any one molecule and its neighbours. SiO_2 is a covalent lattice with strong covalent bonding extending throughout the whole crystal.

Chapter 3

1 *physical*: b, d, e *chemical*: a, c, f

2 chemical: a new substance appears—the reddish-brown solid—and another substance disappears—the one responsible for the blue colour.

3 a chemical; a new substance is formed: the final white substance is different from the starting substance (different melting point). The increase in mass suggests that the original substance reacted with water to form the new substance.

b physical; the original white substance was recovered at the end (same mass and melting point).

5 a the same amounts, namely 14, 7 and 3 all $\times 10^{-19}$ J per atom; because we are just reversing the formation processes, the energy needed equals the energy originally released.

b The chemical bonding is strongest in aluminium oxide and weakest in copper oxide, because the more energy required to break the bond, the stronger the bond is.

6 a i element

ii compound; the original liquid conducts electricity without decomposing so it must be a metal, that is, an element. The white solid decomposes (to silvery droplets and colourless gas) so it is a compound.

b greater (the element combines with oxygen to form the white solid); less (some of it has decomposed by electrolysis).

c conversion of silvery solid to white powder; electrolysis of the white powder.

7 a silver chloride + light $\longrightarrow$ silver + chlorine

8 a ethane + oxygen $\longrightarrow$ carbon dioxide + water
$2C_2H_6(g) + 7O_2(g) \longrightarrow 4CO_2(g) + 6H_2O(g)$

9 a One molecule of butene which contains 4 carbon atoms and 8 hydrogen atoms reacts with 6 oxygen molecules (each containing 2 oxygen atoms) to form 4 molecules of carbon dioxide (each containing one carbon atom and 2 oxygen atoms) and 4 water molecules (each containing 2 hydrogen atoms and 1 oxygen atom).

10 a 2 Cu, 4 N, 12 O

b 8 C, 20 H on both sides, 18 O on left, 26 O on right (a) is balanced, (b) is not (different number of O atoms on the two sides).

11 a KBr **c** Na_2O **e** Li_2S
b ZnO **d** CaH_2 **g** AlF_3

12 a calcium hydride, lithium sulfide, aluminium bromide

b iron(III) oxide, ferric oxide; tin(II) sulfide, stannous sulfide; lead(II) oxide, plumbous oxide (lead oxide is acceptable: see end of Section 3.9); copper(I) chloride, cuprous chloride. The first name is preferred in all cases.

13 a $NaNO_3$ **b** Li_2CO_3 **c** K_3PO_4

14 a zinc sulfate **c** iron(II) hydroxide
b ammonium carbonate **d** aluminium nitrate

15 a i 2 **ii** 1 **iii** 3 **iv** 4 **v** 2
b i 2 **ii** 2 **iii** 1 **iv** 3 **v** 2

16 a zinc oxide, ZnO
b potassium iodide, KI
c aluminium fluoride, AlF_3
d magnesium sulfide, MgS
f iron(II) chloride, $FeCl_2$ and iron(III) chloride, $FeCl_3$

17 a SF_2 **b** NCl_3 **c** Cl_4 **d** BCl_3 **e** SO_2

18 a silicon tetrachloride, carbon disulfide, dinitrogen monoxide, nitrogen trichloride, hydrogen sulfide (though strictly it should be dihydrogen sulfide)

b diphosphorus pentoxide, dinitrogen tetroxide, dichlorine oxide (though often called chlorine oxide), oxygen difluoride

19 a ammonia, NH_3
b silicon tetrabromide, $SiBr_4$

Exam-style questions for Module 1

For answers for all the exam-style sets of questions the procedure will be as follows:

- A reference to the section of the book that treats the topic will be given.
- Then there will be some analysis or commentary of what the question requires such as what the main verb means in the context of the question, how much detail is warranted for the marks allotted, how to divide marks and time between different parts of the question and traps to watch out for.
- For some questions there will be a brief outline of the key points to treat; the amount of detail given here will depend on how directly the material in the section referred to relates to the question asked.
- For other questions a full answer will be given. In these answers there will be superscripted numbers such as $^{(1)}$ $^{(2)}$ $^{(3)}$ which count off the significant bits of information or marks for the answer. Answers quite different from these sample answers are possible and could equally well score full marks. However the sample answers are good guides for what to aim at. They are of a very high standard and less precise or less detailed answers would probably score full marks under exam conditions. Explanations and commentaries are printed blue while sample answers are black.

A similar approach will be used for this type of question in the Revision Tests.

The number of marks for a question determines the amount of time you should spend on it (100 marks for 3 hours work so 1.8 minutes per mark). Another guiding principle this author recommends, though you won't find it in any Board of Studies or HSC document, is that there should be at least **one piece of significant and relevant information per mark**. For a five-mark question three significant bits of information is unlikely to score full marks, five pieces should, seven would be playing it very safe if you could do it in the nine minutes allowed, while ten would be foolhardy: too much time spent on the question at the expense of later questions (and you can't get more than full marks on a question anyway).

1 See Section 1.1. With 6 marks we should think in terms of three characteristics with 1 mark for naming (describing) each and 1 for evaluating its usefulness. There are five characteristics in Table 1.1. Any *three* of the following characteristics plus their evaluations would get full marks. Note that if you are asked to evaluate or assess something, it is essential that you give some form of evaluation even if it seems trite or trivial, because if you don't you will not get full marks.

(i) a mixture can be separated into two or more pure substances by physical or mechanical means such as distillation or dissolving and filtering whereas a compound cannot$^{(1)}$. This is one of the most useful methods of distinguishing between a mixture and a compound because it is based on the fundamental difference between them$^{(2)}$.

(ii) a mixture displays the properties of the pure substances that make it up, whereas a compound has properties that are quite different from those of the substances it was made from$^{(1)}$. This also is one of the most useful methods of distinguishing between them, because it also is based on a fundamental difference between mixtures and compounds$^{(2)}$.

(iii) A mixture can have variable composition, depending on how it was made or where it came from, whereas a compound always has constant composition$^{(1)}$. While often useful this characteristic is not always easy to demonstrate and so it is of less value than the previous two$^{(2)}$.

(iv) The properties of a mixture can change as its composition changes whereas the properties of a compound are always the same$^{(1)}$. This characteristic is of limited use or value because it is often difficult to apply$^{(2)}$.

(v) Mixtures may be heterogeneous or homogeneous while compounds are always homogeneous$^{(1)}$. This characteristic is of limited value because it is only useful if the sample being considered is heterogeneous$^{(2)}$.

2 See Sections 1.7, 1.9 and 1.20. Assume 4 (or maybe only 3) marks for (a) and 2 (perhaps 3) for (b). Even for 4 marks the description in (a) will need to be brief, particularly as diagrams are required.

For (a) filter off the sand and dry it, include a diagram such as Figure 1.3; distil off and collect some of the water, diagram like Figure 1.5; finally transfer the remaining solution to an evaporating basin and evaporate it to dryness, possibly with a diagram like Figure 1.4. Do not distil the solution to dryness (you will crack the flask!)

For (b) weigh the starting mixture, weigh the sand after collecting and drying it, weigh the salt after evaporating off all the water; calculate percentages of sand and salt from mass of each divided by total mass of mixture, then calculate the percentage of water by difference

(% water = 100 – % sand – % salt).

3 See Sections 1.6 to 1.12. Probably 1 mark for each of the four techniques required and 1 mark for the properties of the solids and 1 for the properties of the liquids (HSC examiners do not use half marks). *Outline* means describe briefly (and for the marks allotted you need to be very brief here!). While diagrams are often desirable, you do not really have time to include them in this answer. Note that HSC examiners have recommended (Examiners Report 2001) that 'point-form presentation' be used in appropriate situations (that is, answers in the form of notes are acceptable). For separating solids, instead of the methods below you could use magnetic separation or sublimation; chromatography would probably be acceptable for either solids or liquids (providing there was a solvent that dissolved all components of the mixture).

For separating a mixture of solids:

(i) sieving: for this to work the particles of the solids must have different sizes.

(ii) add a suitable solvent to dissolve one solid but not the other, filter off the insoluble solid, and evaporate the solution of the other solid to dryness. For this to work the solids must have very different solubilities in the chosen solvent.

For separating mixtures of liquids:

(i) distillation: boil the mixture and condense the vapour that comes off: For this to work the liquids must have quite different boiling points so that one vaporises much more readily than the other.

(ii) use a separating funnel: this requires that the two liquids be immiscible; that is, that they separate into two layers when they are left to stand for a while.

4 See Section 1.22. State the relationship (1 mark), explain why it exists (1 mark) and give at least two examples, at least one reactive and one non-reactive (1 mark) (the question said 'examples' so one is not enough).

The more reactive an element is, the less chance there is of finding it on Earth in an uncombined state$^{(1)}$. This is because if an element is reactive, it will combine with many other elements whenever it comes into contact with them and so form compounds$^{(2)}$. Examples: reactive sodium, calcium and chlorine do not occur naturally as free elements but as compounds; unreactive gold and platinum occur as free elements(3).

5 This question is based upon the For Investigation task on page 19 which in turn is based on Section 8.2.1 right-hand dot point 4. There are 7 marks or 12½ minutes for this question so considerable detail is required. However do not overlook the last two parts—what properties … and effect on the environment.

6 See Section 1.20, particularly the worked example. Assume 2 marks for (a) with 3 for (b), so you need at least three bits of information for (b).

a 3.5%

b Identify two sources of error and a way of minimising each (4 bits of information): any two of (i) loss of solution by splashing or spitting, particularly near the end of the evaporation (minimise by heating gently), (ii) incomplete drying of the salt (minimise by weigh, re-heat, weigh until constant mass obtained), (iii) suspended matter may be present and gets weighed as dissolved salt (eliminate by filtering the solution before evaporation).

7 See Section 1.23. Because of the *compare and contrast* do not just list properties: phrase them into comparisons or contrasts. Also because of the *compare*, find one property that the two classes have in common (wide range of melting points). Four of the five statements below would score full marks.

- All metals are solids at room temperature (with one exception, Hg) whereas non-metals can be solids liquids and gases.
- Both metals and non-metals show a wide range of melting points.
- Metals have a shiny lustrous appearance whereas the solid non-metals are usually dull.
- Metals are good conductors of heat and electricity whereas non-metals are non-conductors (except for the graphite form of carbon).
- Metals are malleable and ductile whereas non-metals are not: they tend to be brittle.

8 See Section 1.23. This is compulsory Experiment 3, see page 93. Even with 7 marks (12½ minutes) you need to be brief with your descriptions. Use properties that help distinguish between the three classes of element: solubility in water is not really of much use. The tests you performed probably would not have let you distinguish between the semi-metal and non-metal, so you should say so. Three tests plus the table would probably get you full marks, though four tests would be safer.

The properties that we used and how we measured them were:

(i) appearance: we cleaned the surface with emery paper and observed whether it was shiny and lustrous or dull

(ii) electrical conductivity: we connected the sample in series to a power supply and ammeter and noted the current (if any) that flowed

(iii) hardness: we scratched the surface with a sharp steel knife

(iv) brittleness or malleability: we hit a sample with a hammer to see whether it would flatten or shatter or crush into a powder (see Table below).

Aluminium was a metal, sulfur was a non-metal and boron a semi-metal (though the properties we were able to measure made it look like a non-metal).

9 See Section 1.24. The *assess* is probably worth 2 marks and the examples 3 (1 each).

Physical properties are generally the major factor in choosing a metal for a particular job; however chemical reactivity (corrosion) is often a factor as is cost. There are four examples in Section 1.24, though others are equally acceptable.

10 See Sections 2.12 and 2.13.

Valence electrons are the electrons in the incompletely filled outermost energy level (shell) of an atom.(1) For example in Mg with electron configuration 2, 8, 2, the valence electrons are the two in the third level(2). This concept is very useful because it gives us the number of electrons an element has available for use in chemical bonding without having to work out the full electron configuration(3), this happens because all elements in a group (vertical column) of the Periodic Table have the same number of valence electrons. For example Br has seven valence electrons because it is in the same group as F. This is much simpler than having to get the number of outer shell electrons by working out the electron configuration of Br which has 35 electrons(4).

11 See Sections 2.15 and 2.22. *Describe*, not just *name*: ionic bonding in which an electron is

Sample	Appearance	Conductivity	Hardness	Brittle or malleable
aluminium	shiny	high	soft	malleable
silicon	dull grey	none	hard	hard (did not shatter or flatten)
sulfur	dull, yellow	none	small crystals, could not test	brittle

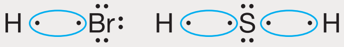
transferred from Na to Cl forming Na^+ and Cl^- (1 mark), then ion packing into an orderly array; draw a diagram (1 mark). Explain each of the three properties as in Section 2.22 (1 mark for each explanation).

12 See Section 2.16. *Discuss*, so you need to consider groups of elements where the table is helpful (1, 2, 7, 6) (1 mark) and show how it is helpful (charge on the positive ion is the group number, on the negative ion 8 minus the group number) (1 mark) and also groups where the table is not of much use (4, 5, and transition elements) (1 mark).

13 See Sections 2.17 and 2.22. *Explain* that covalent bonding involves sharing electrons; the simplest example would be one of Cl_2, HCl, or H_2O, though you could use some other molecule; draw its electron-dot structure (2 marks). With only 2 marks left for properties, you need consider only two properties—low melting and boiling points, softness (in both cases strong bonding within the molecule but only weak intermolecular forces between molecules so they are easily separated from one another), zero electrical conductivity (no ions present and all electrons localised in bonds and unable to migrate) (1 mark for each property with the explanation).

14 See Section 2.20. Assume one mark for each structure and two for the *assess*. The last sentence in the assess (below) is added to be sure of getting the marks.

The electron-dot structures are:



Electron-dot structures are very useful in predicting the formulae of simple covalent compounds(1) because the structures show us how many bonds each atom must form in order to fulfil its drive to noble gas configurations and that leads to the formula(2). In hydrogen sulfide the structure shows that S must form two bonds while each H only needs one bond, so the formula is H_2S.

15 See Sections 2.22, 2.23 and 2.25, particularly Table 2.6. Because of *compare and contrast*, you need to point out similarities and differences: don't just list the properties. For example: ionic solids and covalent network solids have high melting and boiling points whereas covalent molecular solids have low ones. The properties to treat are (i) melting and boiling points, (ii) electrical conductivity, (iii) hardness and (iv) malleability and ductility. If you are doing this test after studying Module 3, you could add solubility in various solvents (Section 7.11, particularly page 000). Three properties properly compared and contrasted would score full marks.

16 See Section 2.23, especially Table 2.6. Explain why no one of these properties alone will do the job. State what each property (test) will tell you about the class a substance belongs to and explain that two properties are needed and which one is essential.

No one of these three properties is able to classify substances into these three classes(1). Each property can identify a substance as belonging to one class but not distinguish between the other two classes(2). The following table explains why(3, 4).

	Melting point	Hardness	Electrical conductivity of molten sample
ionic solid	high	hard	some
covalent molecular solid	low	soft	none
covalent network solid	high	hard	none

Both melting point (low) and hardness (soft) can distinguish a covalent molecular solid from the other two classes; electrical conductivity can distinguish an ionic substance from the other two classes(5). Therefore we need electrical conductivity plus one of the other two tests to classify substances into the three classes. Hence we can say that electrical conductivity is the most useful of these three properties in that we cannot do without it(6).

17 See Section 1.2. This is compulsory Experiment 5 on page 197. Three marks for describing the experiment, 2 for table of results and 1 for extra properties.

If you did the experiment in *CCPC* BLM using magnesium, oxygen and magnesium oxide, describe it. The properties you probably measured were physical state, colour, electrical conductivity, solubility in water, reaction with hydrochloric acid (Mg forms bubbles as it dissolves; MgO dissolves with difficulty but no gas is formed). Properties you would have liked to measure were melting points and densities (of the solids).

An alternative experiment is to make iron(II) sulfide by mixing iron filings and sulfur in a test tube and heating them strongly: use approximately equal masses of Fe and S and burn off the excess S preferably in a fume hood. A black homogeneous solid results. Break the test tube to obtain the lump of black solid. Crush some of it for the chemical test.

Property	Iron	Sulfur	Iron(II) sulfide
colour	shiny grey	yellow	black
conductivity	high	zero	zero
magnetic?	yes	no	no
with HCl	colourless gas (H_2)	no reaction	nasty smelling gas (H_2S)

Again the properties you would have liked to measure were melting points and densities.

18 See Section 3.2, third sub-section. Give three reasons (1 mark each) and draw a diagram similar to Figure 3.5 (1 mark).

19 See Section 3.2. This is compulsory Experiment 4 on page 93. Describe what you did and draw a diagram (3 marks). Write the equation (1 mark). List two or three safety precautions (1 mark).

We put green copper carbonate in a test tube and heated it gently: it turned black.(1) We showed that a gas was produced and that it was carbon dioxide by fitting a gas delivery tube to the test tube and dipping it into a test tube of clear lime water; (draw diagram)(2). We noted the formation of bubbles, which showed that a gas was formed, and that the gas evolved turned the lime water milky, showing that the gas was carbon dioxide(3).

$$CuCO_3(s) \longrightarrow CuO(s) + CO_2(g)^{(4)}$$

The safety precautions we took were (i) we removed the lime water before stopping the heating, (ii) we made sure to point the test tube away from ourselves and our neighbours, and (iii) at the end of the experiment we placed the hot test tube on a heat-proof mat or gauze where no one was likely to accidentally touch it (any two of these gets 1 mark).

20 See Section 3.4. Explain that energy is required to break chemical bonds and so energy is released when bonds form (1 mark). The key to the NO situation is that it is being formed from molecules, not separated atoms.

This is because compounds are more stable than separated individual atoms: energy has to be supplied to break chemical bonds, so when atoms combine to form chemical bonds energy is released.(1).

When NO is formed from N and O atoms, energy is released (because a chemical bond is formed). However nitrogen and oxygen gases do not consist of separated atoms but rather of diatomic molecules, N_2 and O_2(2). So to form NO we have first to break the O—O and N—N bonds and this requires the input of considerable amounts of energy. The energy released when N and O atoms combine to form NO molecules is less than that required to break N_2 and O_2 into atoms and so when these gases combine to form NO energy is absorbed(3).

Module 1 revision test

1 c **2** b **3** a **4** a **5** d
6 c **7** b **8** d **9** b **10** d

11 a 1 is filtration, 2 is distillation
b see Figs 1.3 and 1.5
c barium sulfate

12 a all of them **b** F and Ne

13 See Section 3.2, second sub-section. You need to explain (briefly) how electrolysis shows that water is a compound, then make some comment about how important electrolysis is for showing this and why.

Electrolysis is very important for showing that water is a compound because it breaks water into two different gases, hydrogen and oxygen, which have quite different properties from water.(1) Because electrolysis breaks water into two simpler substances, the elements that make it up, it shows that water is a compound and not an element(2). The great importance of electrolysis for determining that water is a compound lies in the fact that it is the only easily accessible way of decomposing water into its elements.(3) While other methods are possible—heating to extremely high temperatures or irradiating it with very short wavelength ultraviolet light—they cannot be used in school laboratories.

14 a heat calcium carbonate, copper nitrate, lead nitrate; electrolyse water or molten lead bromide
calcium carbonate ⟶ calcium oxide + carbon dioxide
water ⟶ hydrogen + oxygen
b burn magnesium in air
magnesium + oxygen ⟶ magnesium oxide
c We need to supply energy to break chemical bonds; energy is released when chemical bonds form.

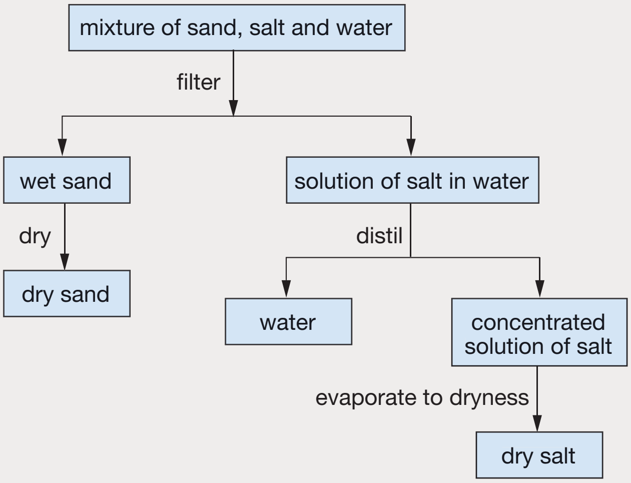
15 a distil them; Fig 1.5
b measure boiling point, distil it (try to purify it), measure boiling point again: if constant then liquid is pure.
c use fractional distillation.

16 a H (1), Na (2, 8, 1), S (2, 8, 6)
b $Na^+ \, :\overset{\cdot\cdot}{\underset{\cdot\cdot}{S}}:^{2-}$ Na_2S $Na^+ \, H:^-$ NaH
c see Figure 7.1; H_2S

17 a 15.6%
b The mass gain in the setting process is 15.7% of the final mass. The equality of these two percentages (within experimental error) shows that the setting process is just the reverse of the original heating process.

18 a *A* is metallic, *B*, *E* are covalent lattices, *C* is covalent molecular, *D* is ionic
b see Sections 2.22 and 2.24
c see Sections 2.22 and 2.24

19 This is based on compulsory experiment 1 on page 92. You probably separated sand, salt and water. Note that the question asks you to *separate* the three components; that means you need a sample of pure water (as well as samples of sand and salt) at the end. Hence you need to filter off the sand and dry it (1 mark), distil off most of the water (to get your sample of water) (1 mark), then evaporate the remaining solution to dryness to get salt (1 mark). And 1 mark for a flow chart. Just evaporating the solution to dryness to recover the salt would not score full marks. A suitable flowchart:


mixture of sand, salt and water
filter
wet sand
solution of salt in water
dry
distil
dry sand
water
concentrated solution of salt
evaporate to dryness
dry salt

20 See Section 1.23. Six marks, so you need six significant bits of information. *Evaluate* so you need to make some comment about their relative usefulness in making decisions. *Include examples* is looking for elements that present difficulties to the different criteria—graphite (carbon) for conductivity, mercury and gallium for melting point.

Appearance and electrical conductivity are both very useful in deciding whether an element is a metal or a non-metal, though one of these alone is not sufficient.(1) Melting point is less useful(2). Metals generally have a shiny lustrous appearance while non-metals generally have dull appearances. In marginal cases such as boron or silicon appearance on its own is not a good criterion to use.(3) Metals are good conductors of electricity whereas non-metals are non-conductors, except for graphite, an allotrope of carbon: it is a conductor(4). Hence conductivity alone cannot classify all elements as metals or non-metals; however, of the three properties it is the most useful(5). Metals generally have high melting points and non-metals low ones; however, there are many exceptions—mercury (liquid at room temperature), gallium and sodium have relatively low melting points while graphite and diamond (carbon, a non-metal) have very high melting points(6). Melting point is the least useful of the criteria given.

Chapter 4

2 **a** high tensile strength
b very high melting point (and moderate electrical conductivity)
c does not tarnish (very non-reactive)

3 **a** good thermal conductivity, resistance to corrosion, strength (to avoid dents and distortions); Al, Cu (Fe if protected from corrosion)
b no; by attaching a layer of copper or aluminium to the bottom of the saucepan

4 Aluminium scratches and dents easily and discolours in automatic dishwashers; 20 years ago stainless steel was so much more expensive than aluminium that it was not widely used for kitchen goods but today the price differential is less and no longer discourages the use of stainless steel. In addition stick-free coatings on tinned steel pots and pans are more durable and protect such items from corrosion, thus making them more attractive to consumers.

5 It's cheaper.

6 **a** sodium, tungsten
b sodium, platinum
c silver, copper, gold
d titanium, iron

7 because they were present on Earth as uncombined elements, so the metal did not have to be extracted chemically from a compound; they were too soft

8 to eliminate the risk of lead poisoning; bismuth and antimony were not known in ancient times

9 **a** $CuO(s) + C(s) \longrightarrow Cu(l) + CO(g)$
b $SnO_2(s) + 2C(s) \longrightarrow Sn(l) + 2CO(g)$
c $Fe_2O_3(s) + 3C(s) \longrightarrow 2Fe(l) + 3CO(g)$
d $Fe_2O_3(s) + 3CO(g) \longrightarrow 2Fe(l) + 3CO_2(g)$

10 $2CuFeS_2(s) + 2SiO_2(s) + 5O_2(g) \longrightarrow$
$2Cu(l) + 2FeSiO_3(l) + 4SO_2(g)$

11 $Cu(OH)_2.CuCO_3(s) \longrightarrow 2CuO(s) + CO_2(g) + H_2O(g)$
$Cu(OH)_2.2CuCO_3(s) \longrightarrow 3CuO(s) + 2CO_2(g) + H_2O(g)$
$CuO(s) + C(s) \longrightarrow Cu(l) + CO(g)$

12 $TiO_2(s) + 2C(s) + 2Cl_2(g) \longrightarrow TiCl_4(g) + 2CO(g)$
$TiCl_4(g) + 2Mg(l) \longrightarrow Ti(s) + 2MgCl_2(s)$

13 **a** $2Ca(s) + O_2(g) \longrightarrow 2CaO(s)$
b $4Fe(s) + 3O_2(g) \longrightarrow 2Fe_2O_3(s)$

14 **a** $2Li(s) + 2H_2O(l) \longrightarrow 2LiOH(aq) + H_2(g)$
b $Ba(s) + 2H_2O(l) \longrightarrow Ba(OH)_2(aq) + H_2(g)$
c $Mg(s) + H_2O(g) \longrightarrow MgO(s) + H_2(g)$

15 **a** **i** $Fe(s) + H_2SO_4(aq) \longrightarrow FeSO_4(aq) + H_2(g)$
ii $Fe(s) + 2H^+ + SO_4^{2-} \longrightarrow$
$Fe^{2+} + SO_4^{2-} + H_2(g)$
iii $Fe(s) + 2H^+(aq) \longrightarrow Fe2+(aq) + H_2(g)$
Spectator ion is SO_4^{2-}; it tells us which acid was used to provide the H^+.

16 **a** *In 13*: Ca, Fe;
In 14: Li, Ba, Mg;
In 15: Fe, Al
Each of these metals has lost electrons to form the positive ion.
b $Fe \longrightarrow Fe^{2+} + 2e^-$; $2H^+ + 2e^- \longrightarrow H_2$

18 **a** Ca; Cu; Ca reacts with water (giving up electrons to it) while the others do not; Cu is the only one that does not react with dilute acids (others give up electrons to H^+)

b Ag^+; Mg^{2+}

21 a $Mg(OH)_2(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + 2H_2O(l)$

$MgCO_3(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + CO_2(g) + H_2O(l)$

b electrolysis of molten $MgCl_2$; electrolysis of a molten salt is difficult and until electricity became relatively cheap in the early part of the 20th century electrolysis was too expensive for magnesium (or aluminium for that matter) to compete with common cheaper metals such as iron and copper.

23 a between Cu and Ag (between Ag and Pt is acceptable)

b left of Zn and right of Ca; harder to extract than zinc, less reactive than calcium

c Ti; the further to the left in the activity series, the more difficult it is to extract the metal from its ore, meaning the more energy is required.

d Hg; the easier a metal is to extract, the earlier in history that humans were able to extract and use it.

25 a Al is more expensive to extract from its ore (both in money and energy terms); additionally steel cans do eventually rust away: Al ones do not.

c Most things made from copper are used for very long times—copper pipes and plumbing fittings typically 100 years, electrical wiring, typically 50 years.

Chapter 5

1 84

2 8 times

3 Calcium atoms have twice the mass of neon atoms.

4 a 119.0 **e** 159.8 **i** 80.0 **m** 132.1

b 44.0 **f** 142.0 **j** 180.2 **n** 342.3

c 95.3 **g** 136.2 **k** 74.1 **o** 286.1

d 78.1 **h** 106.0 **l** 187.6

5 a 0.20 **b** 2.5×10^{-3} **c** 0.47

d 3.5 **e** 89 **f** 5×10^3

6 a 1.9×10^2 g **b** 1.4 g **c** 0.056 g

7 a 1.2×10^{23} **b** 1.5×10^{21}

c 2.8×10^{23} **d** 2.1×10^{24}

e 5.3×10^{25} **f** 3×10^{27}

8 a 1.09×10^{-22} g **b** 3.27×10^{-22}

c 6.64×10^{-24} g

9 5.0×10^{21}

10 a 0.26 mol **b** 0.14 mol

c 0.11 mol **d** 0.11 mol

11 a 4.4×10^2 g **b** 5.0 g **c** 0.052 g

12 a 8.5×10^{22} **b** 2.9×10^{22}

c 9.6×10^{22} **d** 1.8×10^{23}

e 1.4×10^{23} **f** 1.3×10^{23}

13 a 145 g **b** 3.3 g **c** 0.126 g

14 1.5×10^{23} ; 3.0×10^{23}

15 a 2.80×10^{-3} **b** 2.80×10^{-3}

c 8.40×10^{-3}

16 a 2.82×10^{-23} g **b** 1.18×10^{-22} g

c 5.69×10^{-22} g

17 2.5×10^{18}; 1.1×10^{20}

18 a 22.6% **b** 52.9% **c** 80.1%

19 a 63.5% Ag, 8.2% N, 28.3% O

b 34.6% Al, 61.5% O, 3.9% H

c 28.2% N, 8.1% H, 20.8% P, 43.0% O

d 27.9% Fe, 24.1% S, 48.0% O

20 a 21.2% **b** 46.7%; urea

21 18.5%

22 34.6%

23 1.90 t (t = tonne)

24 Cu_2S (79.9%), $Cu(OH)_2.CuCO_3$ (57.5%), $Cu(OH)_2.2CuCO_3$ (55.3%), $CuFeS_2$ (34.6%)

25 $CuCl_2$

26 Ag_2SO_4

27 Mg_3N_2

28 a 4.45 g for Al; 1.35 g for Sn, 1.23 g for Zn, 0.39 g for Pb

b Al_2O_3; SnO_2; ZnO, PbO

29 116% increase for Li, 178% for Be, 66% for Mg, 25% for Cu; atomic weight of the metal and valency of the metal

30 a 3.5; **i** 2 **ii** 3 **b** 125; 90

31 a 60 **b** 0.3

32 a 13 g **b** 2.92 g

33 1.1 g

34 0.040 g; 2.7 g

35 1.03 g; 0.057 g

36 9.96 g

37 0.50 t

38 3.10%

39 72.4% for Fe_3O_4, 70.0% for Fe_2O_3; the concentration of the pure mineral in the ore dug out of the ground, the efficiency of the chemical process for extracting the metal from the pure mineral (compound)

40 8.3 t

41 0.26 t

42 3; because 1 molecule of ozone contributes O atoms to 3 molecules of carbon monoxide

43 2; GO_2; 14; yes, for example G_4 and G_2O_2

44 a $Fe_2O_3(s) + 3CO(g) \longrightarrow 2Fe(l) + 3CO_2(g)$; 5.0 L

b $Ni(s) + 4CO(g) \longrightarrow Ni(CO)_4(g)$; 8.0 L

Chapter 6

2 between As and Se; because As is a semi-metal and Se a non-metal, and putting In after As puts it in a group of atoms (O, S, Te) with which it has no similarities, and it pushes Se and Br out of groups of atoms to which they do have similarities (O, S, Te and F, Cl, I respectively).

113 (to calculate this let the atomic weight be *x*, express molecular weight and hence % In in terms of *x*, equate % In to 82.5% and solve for *x*); between Cd and Sn; puts it between other metals and into a group of metals (Al, Ga, Tl) to which it has some similarities.

3 A whole group of the table was missing so it did not push other elements into wrong groups.

4 a Density generally increases going down a group, though there can be deviations particularly in Periods 2 and 3.

b Fr 2.5 g/mL, Ra 4.5 g/mL (both ± 0.5); these estimates are not very accurate, because there is not a simple relation between period number and density as shown by the fact that the points do not lie on smooth curves: hence extrapolation is not very reliable.

5 b Molar volume increases as period number increases.

6 a Be^{2+}, Rb^{+}, Ga^{3+}

7 a i Mg, Ca, Ba **ii** Cl, P, Al **iii** S, Al, Na, Rb

b i Ba, Ca, Mg **ii** Al, P, Cl **iii** Rb, Na, Al, S

8 *A* and *D*, Group 1; *B*, Group 2; *C*, Group 0

9 17, 1300; 18, 1500; 19, 400; 20, 600; use atomic numbers to work out the electron configurations and so assign the elements to groups (17 to Group 7, 18 to 0, 19 to 1 and 20 to 2), then use the way first ionisation energy varies across the periods to assign the values to the elements.

11 *X*: 425, 230; *Y*: 740, 160; *Z*: 1260, 100

12 a Sr, 2; As, 3 or 5; Se, 2; In, 3; Br, 1; Cs, 1; B, 3; Ba, 2; Sb, 3 or 5; Ge, 4; Ga, 3; I, 1

b i Sr, In, Cs, Ba, Ga

ii As, B, Ge

iii Se, Br, Sb, I (putting Sb in (ii) or Ge in (iii) is acceptable)

13 a Rb_2O, CsCl, Li_2SO_4, $RbNO_3$, Li_2S

b $Ba(NO_3)_2$, RaO, SrO, $BeSO_4$, $RaCl_2$, $SrBr_2$, BaF_2

14 a PH_3, AsH_3, SbH_3

15 a LiI, NaI, KI, RbI, CsI; ionic

b BeO, MgO, CaO, SrO, BaO; ionic

c MgF_2, $MgCl_2$, $MgBr_2$, MgI_2; ionic

16 b

17 a NaH, ionic; MgH_2, AlH_3, ionic (but with some covalent character); SiH_4, PH_3, H_2S, HCl, all covalent

18 c Fr, 0.7 to 0.78; Ra, 0.80 to 0.84; estimates are not very reliable because they are based upon extrapolations and because curves of different shapes can be drawn through the points.

19 a NH_3, PH_3, AsH_3; covalent; elements in the centre groups of the Periodic Table (particularly Groups 4 and 5) generally form only covalent compounds

b $MgCl_2$; $CaCl_2$; $SrCl_2$, NCl_3, PCl_3, $AsCl_3$; first three ionic, last three covalent; elements in Groups 1 and 2 form only ionic compounds, while elements in Groups 4 and 5 generally form only covalent compounds

Exam-style questions for Module 2

See explanatory notes under Exam-style questions for Module 1.

As in previous Exam-style answer sets, superscripted numbers count the 'significant facts' (or marks) in each answer.

1 See Sections 4.1 (particularly Table 4.1), 4.2 and 4.3. Before you start writing jot down uses where you can easily explain how the properties of the metal make it particularly suited for that use. In other words think about the *list* and *explain* together. One mark for each use *plus* explanation.

2 See Sections 4.1 and 4.4 (and to a lesser extent 4.2 and 4.3). Note that it is *assess*, not just *describe*, so you need to make some judgement about how important alloys are or were. The ancient example has to be bronze, the only significant alloy used before 1000 BCE. Modern examples could be alloys of aluminium, magnesium or titanium or steels, but be careful with steels—many were in use before 1900 CE—though stainless steel would be safe. Brass also is not a post-1900 alloy. Mix the examples in with the assessment. Assume 1 mark for each example and 3 for the assessment. Titanium or magnesium alloys could be used as alternatives to stainless steel and aluminium alloys in the answer below.

Alloy making has been extremely important throughout history(1). Bronze, an alloy of copper and tin, was so important in ancient times that it led to the use of the term 'the Bronze Age'. Bronze was important because it was harder than copper and other metals available before 2000 BCE, and it had a lower melting point and so was easier to make into tools and weapons. Nations that first developed bronze weapons quickly dominated the western world(2).

In modern times alloys are perhaps even more important. Today most metals are used as alloys rather than as pure metals(3), for example iron, aluminium, titanium, magnesium. This is because alloys can be 'tailor-made' to have more desirable properties than the pure metals themselves and so can better meet the needs of modern technology such as high speed aircraft, electronics and body implants(4). Stainless steel, an alloy of iron, chromium and nickel, combines the good properties of iron (strength and hardness) with resistance to corrosion and the ability to take (and keep) a high polish; it is in widespread use both industrially and domestically(5). Alloys of aluminium (mostly aluminium but with small amounts of copper, magnesium and/or manganese) are in widespread use in the aircraft and building industries because of their low density combined with high tensile strength and corrosion resistance(6).

3 See Section 4.4. Assess its suitability, explain why and suggest a better date.

From a chemist's viewpoint 1 CE is not at all suitable for an end date for the iron age(1). Nothing happened chemically around about 1 CE to warrant ending the iron age at that date. Over the next 1900 years there was a gradual improvement in the technology of extracting iron, using it and making various steels, and iron was by far the most dominant metal(2). Chemically a much better date for ending the iron age would be about 1900 CE when aluminium started to become widely used industrially. This was also about the start of the time at which many other metals began to be used industrially also, such as tungsten, magnesium and titanium(3).

4 See Section 4.15. Primarily because it is now possible to extract many more metals from their ores on a commercial scale than it was 200 years ago when heating with carbon was the only industrial process available. *Example***s** means more than one; marks available suggest no more than two. Aluminium (or magnesium) is now available because electrolysis can be used commercially. Titanium is available because advanced technology allows the commercialisation of a tricky laboratory extraction process.

5 See Sections 4.4 and 4.15. *Analyse the reasons* here means explain how and why it happened. Titanium is the obvious choice, though magnesium is an alternative. For titanium the steps were (i) demand (for military aircraft) for a strong, light-weight, high melting point non-corroding metal and there were no serious cost constraints, (ii) development of a method of extracting titanium from its ores, (iii) with the availability of the metal came additional uses which caused the cost of extraction to fall (economies of scale) and hence for even more uses to develop (from artificial body parts to racing bicycles to civilian aircraft). One mark for each step.

6 See Section 4.3. Two marks for car bodies, 2 for drink containers. *Discuss* means point out the pros and cons of the metal for the use.

Iron in the form of mild steel is very suitable for making car bodies in that it is strong, it can easily be stamped into the required shapes and it is relatively cheap. Its main disadvantage is that it tends to corrode unless properly protected(1). Aluminium is much less suitable for car bodies because it is fairly soft and easily dented and distorted; these properties plus its greater cost would outweigh its advantages of low density and resistance to corrosion(2).

Aluminium is very suitable for drink containers because it is very light, can easily be stamped into the required shape and is very suitable for making ring-pull opening tabs, though its relatively high cost is a disadvantage(3). While iron has some properties that would make it suitable for drink containers, such as ease of stamping into shapes and cheapness, it has the disadvantage of making the cans heavier and not being suitable for ring-pull opening tabs, so on balance aluminium is more suitable than iron for this use(4).

7 See Section 4.4. Seven marks here means at least seven significant bits of information. *Outline* means be brief, but bring it right up to the present; *relate* means show the connection between. Assume 4 marks for the chronology and 3 for the *relate*. Only approximate dates are required: copper since 3000 BCE, bronze since 2000 BCE, iron since 1000 BCE, alloy steels since 1880s, aluminium since 1900, titanium since 1950s. These are the key metals to mention, because they are the ones where chronology is easily related to ease of extraction. For *relate*:

This chronology shows that the sequence in which metals came into widespread use reflects the ease with which the metals can be extracted from their ores. Of the ones listed copper is the easiest to extract—just heat the ore with charcoal (carbon); bronze requires heating copper and tin ores, a little more difficult(1). Iron is also extracted by heating with carbon but a significantly higher temperature is required, making the process more difficult and so iron came into use later(2). Aluminium (and magnesium also) cannot be extracted by heating with carbon but requires electrolysis of a molten compound; this was difficult to do and so aluminium did not come into widespread use until the beginning of the 20th century(3). The chemistry for extracting titanium is quite complex and on an industrial scale requires specialised materials; in addition it requires magnesium as a reactant and so titanium is the most difficult of the metals discussed to obtain.

You would probably get full marks without mentioning titanium.

8 See Sections 4.9 and 4.11. This is compulsory Experiment 1 on page 92. Describe the experiment you performed, including what you observed when reaction occurred. Make sure you *explain* how your results determined an order of activity. Seven metals are used below; you only need five, but make sure you include one that reacts with water (Ca or Na) and one that does not react with dilute acid (Cu). For establishing your activity series you could include some results from experiments you did not actually perform (syllabus document allows this here). In questions based on experiments you performed, the one bit of information per mark rule does not apply: you will often have to give more bits of information than that—you have to describe the experiment completely (though briefly if marks are few).

The metals that we examined were Na, Ca, Mg, Fe, Zn, Pb and Cu. We first dropped small samples of the metals to be tested into water in test tubes and noted whether any bubbles of colourless gas (hydrogen) formed (that is, if any reaction occurred)(1). Sodium (demonstrated by our teacher) and calcium were the only metals to react. Because these two reacted with water while the others did not, we decided that these were the most reactive metals(2). Then we dropped samples of the other metals into dilute hydrochloric acid and again noted whether bubbles of gas formed(3). Mg, Zn and Fe reacted but Cu and Pb did not. For these two we heated the test tube to see whether the metals would react with hot acid; Pb did but Cu did not. On the basis of reaction with dilute acid, we decided that Mg, Zn, Fe were more reactive than Pb which in turn was more reactive than Cu(4). Finally we tested Mg, Zn and Fe for reaction with oxygen; we heated samples of these metals in a Bunsen burner flame (holding the metal just above the actual flame)(5). The Mg ribbon burnt while the Zn and Fe just slowly lost their shiny appearance; all three metals reacted with oxygen, the Mg more vigorously than the other two so we decided that Mg was more reactive than Zn and Fe(6).

The activity series that our experiments produced was:

Na = Ca > Mg > Zn = Fe > Pb > Cu(7)

9 See Section 4.13. Any two of the four situations described there will suffice (there are others that are equally acceptable). One mark for describing each situation and one for assessing its importance.

10 See Section 4.12. In *assessing* … make sure you let the examiner know that you know what first ionisation energy is. The last sentence below is probably not necessary.

The first ionisation energy is very useful in estimating the relative reactivities of a set of metals, because the lower the first ionisation energy, the more reactive the metal is(1). This correlation occurs because both first ionisation energy and reactivity of metal are measuring the same thing, the ease (or difficulty) with which an electron can be removed from a metal atom(2). This correlation is useful because if we know the first ionisation energy of a metal we can make an estimate of how readily it will react with a variety of substances, such as water, oxygen and dilute acid.

11 See Section 6.1. *Evaluate* the contributions; do not just describe, but make sure you mention what their contributions were.

The contributions of Dobereiner and Newlands in developing the Period Table were significant but they were by no means the major contributions(1). In developing his ideas of triads, sets of three elements with very similar properties, Dobereiner drew attention to the fact that there were families of elements with similar properties, a key idea for the Periodic Table(2). Newlands with his law of octaves, that every eighth element is a kind of repetition of the first, drew attention to the concept of periodicity, that elements with similar properties recurred periodically when the elements were listed in order of increasing atomic weights(3). These two ideas of similarity in properties and the periodicity of that similarity were the foundations upon which Lothar Meyer and Mendeleev later built. So the contributions of Dobereiner and Newlands were important in laying those foundations(4).

12 See Section 6.1. Mention Dobereiner's triads of elements of similar properties, Newland's ideas about periodicity (Law of Octaves), Mendeleev's table (with his key idea of leaving gaps for undiscovered elements), the foundation of the modern table, Lothar Meyer's similar table and finally Moseley's contribution. Two marks for Mendeleev and one each for Dobereiner, Newlands and Moseley.

13 See Section 6.1. Describe, 2 marks; evaluate, 2 marks; properties, 2 marks.

Mendeleev drew up a table of the elements, listing them in order of atomic weights and starting new rows so that elements with similar properties fell under one another(1). He left gaps in the table for undiscovered elements when this was necessary to keep elements in their 'right' groups(2). He postulated a periodic law: properties of the elements vary periodically with their atomic weights(alternative 2).

Evaluation: This was one of the great chemical achievements of the 19th century. It provided a basis for systematising chemistry and the table (in modernised forms) is the most widely used tool in chemistry today(3). His work highlighted possible discrepancies in properties and atomic weights which stimulated research and the gaps he left in his table led to searches for new elements(4).

The data available to Mendeleev were atomic weights, melting and boiling points of many elements(5), atomic volumes (atomic weight/density), valencies (based mainly on oxides, hydrides and chlorides) and metallic or non-metallic characteristics(6).

14 See Section 6.4. *Assess*, so some judgement is required. Then give reasons for your assessment.

For some elements (those in Groups 1, 2, 6, 7) the table is very useful for working out valencies(1), for others (those in Groups 3, 4, 5) it is of considerable value but for still others (the transition elements) it is of little help at all, so overall the table is moderately useful(2).

To illustrate: Elements in Groups 1 and 2 always have valencies of 1 and 2, elements in Groups 6 and 7 usually have valencies of 2 and 1 (though oxides and oxyacids with different valencies exist). In Group 5 valencies are usually 3 or 5 but nitrogen can display valencies of 1, 2 and 4 also(3).

15 See Section 5.4. Define it (1 mark); give a reason why it's useful, 1 mark.

The mole is useful because it is a quantity of any substance that contains a constant number of particles, be they atoms, ions or molecules. If an equation tells us that molecules react in a certain ratio, then we know that the substances react in the same ratio by moles. Moles help us do chemical calculations.

16 This is compulsory Experiment 2 on page 92. There are two relevant equations (1 mark each) leaving only 3 marks for describing the experiment so you can be brief.

We placed some of the green carbonate ore in a crucible (or test tube) and heated it with a Bunsen burner with occasional stirring until it went fully black (formation of copper oxide) (draw a diagram of your apparatus). The equation is:

$$CuCO_3(s) \longrightarrow CuO(s) + CO_2(g)$$

We dug a hole in a carbon block, mixed the black copper oxide with some of the powdered carbon and put it in the hole, then heated it with a Bunsen burner played directly onto the mixture for several minutes. (Draw a diagram.) Then we tipped the powder onto a white ceramic tile and spread it out and inspected it. There were small shiny reddish-brown globules present. This was copper.

$$CuO(s) + C(s) \longrightarrow Cu(s) + CO(g)$$

You may have used an alternative method of obtaining copper from the oxide:

The black copper oxide was added to a quantity of dilute sulfuric acid in a beaker and gently heated and stirred until a clear blue solution was formed. A zinc rod was then placed in this copper sulfate solution for about 20 minutes. (Draw a diagram.) When the rod was removed from the solution it was covered with a reddish-brown deposit of copper.

$$CuO(s) + H_2SO_4(aq) \longrightarrow CuSO_4(aq) + H_2O(l)$$

$$Zn(s) + Cu^{2+}(aq) \longrightarrow Cu(s) + Zn^{2+}(aq)$$

17 See Section 4.15. Make an assessment (1 mark), then justify it with examples (3 marks).

The ease or difficulty of extracting a metal is much more important than its abundance in the Earth in determining its commercial availability(1). This is demonstrated by iron, aluminium and titanium; these metals are all among the ten most abundant elements in the Earth. Iron is relatively easy to extract from its ore (heat with carbon) and has been in use since about 700 BCE(2). Aluminium is much harder to extract (requires electrolysis of molten aluminium oxide) and as a result has been available commercially only since late in the 19th century. Titanium is even harder to extract and so has only been commercially available since the 1950s(3). Even for metals, such as gold, platinum and palladium, where at first sight it might seem that abundance (or scarcity) is the most important factor, the difficulty of extraction is a still a very major factor in determining their commercial availability(4). In these cases extraction means separating the small concentrations of the metal from the other substances it occurs with, rather than chemical extraction from a compound.

18 See Section 4.17. *Justify* here means give reasons for. The three reasons in this section would score full marks.

19 See Section 4.16. One mark for each of two reasons (proposals). Alternative acceptable reasons are having to mine ores that contain less metal, and the imposition of environmental controls on the mine that increase the cost of production to above market price of the metal.

One reason is that the price of the metal may fall because of declining world demand for it and so reduce the sale price of the metal below the price of production. A second reason is that the development of new technology may allow the metal to be extracted at a much lower price than previously, so that a mine that had been closed because its cost of production of the metal exceeded the market price of the metal could become economic again with the new lower-cost technology.

20 See Section 4.17 and Table 4.7 in Section 4.8. Three marks so you should be looking for three reasons. The last paragraph below is for your information and is not needed for the answer.

The cost of aluminium obtained from recycled materials is a smaller percentage of the cost of new aluminium obtained from its ores than is the cost of recycled steel as a percentage of new steel; in other words there is a greater cost advantage in recycling aluminium than recycling steel(1). In addition there are greater energy savings to be made by recycling aluminium than recycling steel(2). Another factor is the widespread use of aluminium for drink containers, which if not recycled would quickly become a blot on the landscape (they do not corrode) or clutter up garbage tips. In fact the great emphasis on recycling aluminium is targeted at just this use and recycling aluminium is something consumers hear a lot about because it is targeted at them(3).

Actually the greater emphasis on recycling aluminium may be more apparent than real, because it is targeted at consumers. There is a tremendous amount of recycling of steel but it is mainly done by industry and junk car yards so consumers hear much less about it.

Module 2 revision test

See page 315 for an explanation of the approach being used for answers to extended response questions.

1 c **2** c **3** d **4** c **5** a
6 b **7** b **8** a **9** b **10** d

11 See Section 4.6. *Outline* means that you do not have to give much detail. One mark for the equation leaves 3 for the *outline*. You could use either chalcopyrite or copper(I) sulfide. Either one of the equations below would suffice.

The ore is mined and crushed, then concentrated, generally by froth flotation(1). If the mineral is $CuFeS_2$, it is heated with sand (SiO_2) and air to remove Fe(2).

$$2CuFeS_2(s) + 2SiO_2(s) + 3O_2(g) \longrightarrow Cu_2S(l) + 2FeSiO_3(l) + 3SO_2(g)$$

The copper(I) sulfide is then heated alone with more air to form copper(3).

$Cu_2S(s) + O_2(g) \longrightarrow 2Cu(l) + SO_2(g)$(4)

If the ore had contained Cu_2S instead of $CuFeS_2$, then the first heating with sand would not have been needed.

12 See Section 4.9. Describe what you would actually see: the only interpretations required are the equations.

a **i** and **ii** rapid formation of bubbles of colourless gas and the Li goes into solution(1)

$2Li(s) + 2H_2O(l) \longrightarrow 2LiOH(aq) + H_2(g)$(2)
$2Li(s) + 2HCl(aq) \longrightarrow 2LiCl(aq) + H_2(g)$(3)

b **i** no observable change (no reaction)

ii rapid formation of bubbles of colourless gas and the Mg goes into solution(4)

$Mg(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2(g)$(5)

c **i** and **ii** no observable change (no reaction)(6)

13 **a** *A* is argon, *B* is aluminium, *C* is chlorine

b *A*, 94, 1526; *B*, 143, 580; *C* 99, 1260; atomic radius decreases from left to right across a period: ionisation energy increases.

14 **a** 288.9 **b** 31 **c** 8.3×10^{21}

15 This refers to compulsory Experiment 3 on page 177. Assume 1 mark for *major source of error* and *try to minimise it* and 2 marks for listing measurements and explaining; this leaves only 2 for the description so it can be brief.

We placed a weighed quantity of magnesium in a crucible and heated it gently until it started to burn(1). When it had burnt completely we weighed the crucible plus the final product(2). The measurements we made were:

Mass of crucible = m_1; mass of crucible plus magnesium = m_2; mass of crucible plus magnesium oxide = m_3(3)

$$\text{Percentage Mg} = \frac{m_2 - m_1}{m_3 - m_1} \times 100 \quad \text{percentage O} = 100 - \%\text{Mg}^{(4)}$$

The major source of error was loss of magnesium oxide as the metal burnt. We minimised this by keeping the lid on the crucible as much as possible while still admitting enough air for the magnesium to burn completely(5).

16 See Section 4.16, last sub-section. The *explain why* would score 1 mark, leaving 3 for outlining the steps. The four steps in the text can easily be recast into three: the essential features are collect, transport, clean, re-smelt. Emphasis on recycling aluminium? Because of its widespread short-term use in drink containers. The common uses of copper (electrical wiring and plumbing pipes) and zinc (galvanising and alloys) are generally very long term.

17 **a** 116% for Li, 40% for Ca, 24.5% for Zn

b (ii) and (iv)

18 See Section 5.12. You need to state (very briefly) what their contribution was (1 mark), evaluate it (1 mark) and give a reason or example to justify your evaluation (1 mark). The last sentence below is not really necessary; it just makes sure of the marks.

Gay-Lussac's Law of Combining Volumes and Avogadro's hypothesis that equal volumes of gases contain equal numbers of molecules allowed chemists to work out the ratios in which gaseous elements and compounds reacted, and this led to the deduction of formulae for the species involved(1). Their work was extremely important(2) for the determination of formulae, because before it chemists had no way of deciding whether water was H_2O with atomic weights 1 and 16 or HO with atomic weights 2 and 16(3). Their work also led to the conclusion that many gaseous elements contained diatomic molecules such as O_2, H_2 and Cl_2.

19 See Sections 4.1, 4.2 and 4.3. One mark for each of the six uses with the explanation of why the metal is particularly suited for that use. Hence select metals and uses with the explanations in mind. Iron, aluminium and copper are the obvious choices.

Chapter 7

1 **a** For water: 0.996, 1.000, 1.052, 0.992 g/mL; average = 1.01 g/mL; range 0.99 to 1.05

For ice: 0.89, 0.95, 0.92, 0.96 g/mL; average = 0.93 g/mL; range 0.89 to 0.96

b Repeating the measurements several times; do more repeats

c *For ice*: measuring the volume of the ice cube (only ± 1 or 2 mL, about 5 to 10%), some of the ice on the surface of the cube would have melted before the volume had been measured. The low accuracy in volume measurements would just lead to random errors; the melting of the ice would lead to results being consistently high (volume too small so density too high). Minimise volume inaccuracy by using the biggest ice cubes that would fit into the measuring cylinder; minimise melting error by being as quick as possible in measuring volume; using cool water would slow down melting (but not so cool that dew formed on the cylinder).

For water: measuring the volume: not filling the pipette accurately or not draining it consistently. This would just lead to random errors, because some volumes would be slightly large and some slightly small. Minimise by taking great care in filling and emptying the pipette.

The density of water would be the more accurate, because measuring its volume involves less error than measuring the volume of ice and there is no systematic error for the water measurement.

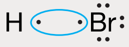
2 0.998 g/mL, 0.918 g/mL

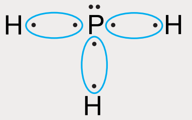
3 **b** It means that water bodies freeze from the top down and that aquatic life forms are able to exist even when surface temperatures fall below 0°C, because water can remain as liquid beneath surface ice. When the surface temperature falls below 4°C, convectional cooling of the water body stops, because the water on the surface has a lower density than that below it and so does not sink. Water is a poor conductor of heat so the water below the surface cools only slowly, despite the top layer cooling rapidly. Consequently water bodies freeze from the top down. This means that generally there is liquid water below the ice for fish and other aquatic life to live in.

4 **b** 19.2 ± 0.5 g; 101.7 ± 0.2°C (Remember that 0 g, 0°C and 0 g, 100°C are points on your curves)

c to raise the boiling point of the coolant so it will operate at a higher temperature than water alone, and to lower the freezing point so that the coolant will not freeze overnight in the engine block when the car is in low-temperature regions such as on skiing trips

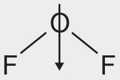
d Anti-freeze has a higher boiling point than water does so when the mixture is boiled, it is water alone that vaporises off. This makes the solution more concentrated in anti-freeze and so the boiling point increases. For pure water there can be no change in concentration so the water continues to boil at the same temperature until it has all vaporised.

5 **a**  HBr

b  PH_3

6 $^{\delta-}F-O^{\delta+}$ $^{\delta+}Cl-O^{\delta-}$ N—Cl (none)
$^{\delta-}N-H^{\delta+}$ $^{\delta-}S-H^{\delta+}$ C—S (none)

7 **a** a, c, d; $\underset{\longrightarrow}{H-Br}$ $\underset{\longrightarrow}{O-F}$ $\underset{\longrightarrow}{C-Br}$;
net dipole: $\underset{\longrightarrow}{H-Br}$ and OF_2

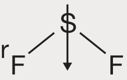


b **i** bond and molecule non-polar

ii polar bond $\underset{\longrightarrow}{B-Cl}$; molecule is non-polar

iii polar bond $\underset{\longrightarrow}{Si-Cl}$; molecule is non-polar

iv polar bond $\underset{\longrightarrow}{S-F}$; molecule is polar



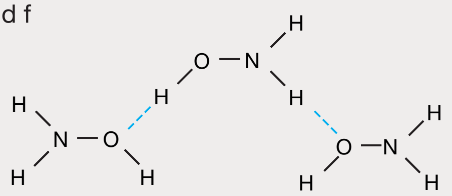
8 **a** Intermolecular forces are greater in sulfur dioxide, hydrogen iodide and CCl_2F_2.

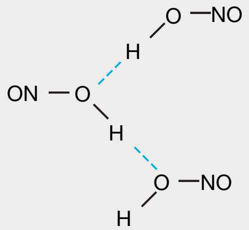
b In He, Ne, H_2 dispersion forces; in SO_2, HI, CCl_2F_2 dispersion forces plus dipole–dipole attractions.

9 CH_4, SiH_4, GeH_4, SnH_4 show the normal trend of boiling point increasing with molecular weight. In the HF, HCl, HBr, HI series HF is anomalous in that its boiling point is +19°C whereas the trend line suggests it should be about −100°C. Explanation: there is hydrogen bonding in HF.

10 Presents evidence for hydrogen bonding in H_2O and NH_3.

11 b and f





13 HBr and H_2SO_4 (both polar and react with water); $MgCl_2$ and $ZnBr_2$ (both ionic); H_2O_2, fructose and urea (polar and form hydrogen bonds with water)

14 **a** $FeSO_4.7H_2O$ **b** $Mg(NO_3)_2.6H_2O$

15 Vitamins C and B must be polar molecules able to form hydrogen bonds with water or they could possibly be ionic (B_1 is).

17 $H_2SO_4(l) + H_2O(l) \longrightarrow H_3O^+(aq) + HSO_4^-(aq)$
(or $H_2SO_4(l) + 2H_2O(l) \longrightarrow 2H_3O^+(aq) + SO_4^{2-}(aq)$)

Chapter 8

1 *soluble*: b, c, f, g, h, k, l, o

2 **a** CuS **b** $MgSO_4$ **c** $AlCl_3$
d FeS **e** $Zn(OH)_2$ **f** $Cu(NO_3)_2$
g $CaBr_2$ **h** KI **i** $Fe(OH)_3$
j $PbSO_4$ **k** $(NH_4)_2S$ **l** Na_3PO_4
m $Mg(OH)_2$ **n** AgBr **o** $Ba(OH)_2$

3 **a** sodium nitrate and magnesium sulfate

b barium chloride and potassium hydroxide

4 **a** lead sulfate, $PbSO_4$

b zinc carbonate, $ZnCO_3$

c no precipitate

d iron(II) hydroxide, $Fe(OH)_2$

5 **i** **a** $Pb^{2+} + 2NO_3^- + 2NH_4^+ + SO_4^{2-} \longrightarrow PbSO_4(s) + 2NH_4^+ + 2NO_3^-$

d $Fe^{2+} + 2Cl^- + 2Na^+ + 2OH^- \longrightarrow Fe(OH)_2(s) + 2Na^+ + 2Cl^-$

ii **a** $Pb^{2+} + SO_4^{2-} \longrightarrow PbSO_4(s)$

d $Fe^{2+} + 2OH^- \longrightarrow Fe(OH)_2(s)$

6 **i** **b** $ZnSO_4(aq) + Na_2CO_3(aq) \longrightarrow ZnCO_3(s) + Na_2SO_4(aq)$

ii **b** $Zn^{2+} + CO_3^{2-} \longrightarrow ZnCO_3(s)$

7 **a** barium chloride and sodium carbonate (or barium nitrate and potassium carbonate)

b silver nitrate and potassium bromide (or sodium bromide)

8 **i** **a** $Ba^{2+} + CO_3^{2-} \longrightarrow BaCO_3(s)$

b $Ag^+ + Br^- \longrightarrow AgBr(s)$

ii **a** $Ba^{2+} + 2Cl^- + 2Na^+ + CO_3^{2-} \longrightarrow BaCO_3(s) + 2Na^+ + 2Cl^-$

b $Ag^+ + NO_3^- + K^+ + Br^- \longrightarrow AgBr(s) + K^+ + NO_3^-$

9 $Ag^+ + CH_3CO_2^- \longrightarrow AgCH_3CO_2(s)$ (or $CH_3CO_2Ag(s)$)
0.100 mol; the reaction did not go to completion
yes; yes. The first experiment shows that the solubility of silver acetate is 0.045 mol/L (0.100 – 0.055), so in the second experiment this amount would dissolve leaving 0.155 mol solid at the bottom of the container. There is an equilibrium between the solid and the solution.

10 **a** The reaction is reversible and comes to equilibrium.

b Brown colour (due to I_2) would develop.

c (ii); when equilibrium is reached, both the forward and reverse reactions are occurring (but at equal rates). Therefore some arsenious acid is converted to arsenic acid and so some radioactivity is transferred to the arsenious acid.

12 **a** **i** 9.7 g/100 mL **ii** 97 g/L

iii 9.7%(w/v)

b **i** 16 mL/100 mL **ii** 12.5 g/100 mL

iii 160 mL/L **iv** 16%(v/v)

13 **a** 1.3 g **b** 14 g **c** 0.38 g

14 **a** Dissolve 8.8 g ammonium chloride in water and make up to 250 mL in a volumetric flask.

b Mix 75 mL ethanol with water and make the volume to 500 mL; 25 mL pipette for ethanol (fill 3 times), 500 mL volumetric flask for the solution.

15 **a** Dissolve 20 g sodium carbonate in water and make volume to 250 mL.

b Pipette 25 mL of this 8% solution into a 500 mL volumetric flask and add water to the 500 mL mark.

c 20 mL of the solution (fill a 10 mL pipette twice) diluted to 50 mL in a volumetric flask, or 100 mL (4 × 25 mL pipette) diluted to 250 mL (volumetric flask)

16 **a** 3.2×10^{-3} g

b It is hard to measure this small mass accurately. Make a 200 ppm solution by dissolving 0.32 g in exactly 1 L then dilute it by 100: 10 mL pipette into a 1 L volumetric flask.

17 **a** 2.0 mol/L **c** 2.04 mol/L **e** 0.0588 mol/L

b 0.75 mol/L **d** 1.20 mol/L **f** 0.700 mol/L

18 **a** 0.800 mol **b** 0.125 mol **c** 6.25×10^{-4} mol

19 **a** 36.5 g **b** 15 g **c** 15.4 g

20 **a** 2.65×10^{-3} mol **c** 2.8×10^{-3} mol

b 3.5×10^{-4} mol **d** 0.66 mol

21 **a** 0.106 g **c** 0.26 g

22 **a** **i** 5.84×10^{-4} mol **ii** 5.84×10^{-4} mol

iii 1.17×10^{-3} mol

b **i** 4.22×10^{-3} mol **ii** 4.22×10^{-3} mol

iii 8.45×10^{-3} mol

23 **a** 0.0106 mol/L **c** 0.122 mol/L

b 5.58×10^{-3} mol/L **d** 0.0304 mol/L

24 **a** 25 mL to 250 mL

b 25 mL to 1000 mL

c 50 mL to 250 mL or 100 mL to 500 mL

25 **a** 0.0163 mol **b** 6.36×10^{-3} mol

c 2.18×10^{-3} mol

26 **a** 3.80 g **b** 0.232 g

27 **a** 0.590 mol/L **b** 14.3 g/L

28 **a** 0.261 mol/L **b** 0.277 mol/L

29 5.74 g/100 mL

30 3.3×10^2 kJ

31 **a** 2.0×10^3 J **c** 3.8×10^4 J **e** 4.0×10^2 J

b 1.3×10^2 J **d** 3.6×10^3 J **f** 1.9×10^5 J

32 2.47 J K^{-1} g^{-1}

33 a, d exothermic, ΔH negative; b, c endothermic, ΔH positive; temperature falls because the heat that needs to be absorbed to dissolve the solid is taken from the thermal energy of the liquid and solid and so the temperature falls.

34 **a** –75 kJ/mol **b** +43 kJ/mol **c** –15 kJ/mol

36 **a** 33°C

b 3.6°C

Exam-style questions for Module 3

1 See Section 7.1. *Outline* means describe briefly. Four marks suggests four significant bits of information, so mention water as a raw material (chemical reactant), a solvent for life processes, a transport medium, a thermal regulator and as a habitat for some life forms (that's five!).

2 See Section 7.8. Assume 3 marks for living matter and 3 for industrial activities. *Discuss*, so don't just describe the ways in which water is important—explain *how important* it is and *why* it is important.

Water is so important as a solvent in living matter that without it there would be no life on Earth as we know it(1). Water is the solvent in which almost all of the chemical reactions that are part of living matter occur; without it these reactions could not occur(2). Water is the solvent that carries nutrients (as solutes) to the various cells of organisms and it is also the solvent that carries waste products away from cells(3).

Water is a very important solvent in industry, though probably not as vital as for living matter(4). Common fertilisers such as ammonium sulfate are made in aqueous solutions, as are the acids and alkalis that industry uses in large amounts. Making these substances would be much more difficult (though not impossible) without water as a solvent(5). Aqueous solutions are often involved in some stages of the extraction of certain metals from their ores; examples are aluminium and uranium. Other metals such as copper are refined using aqueous solutions. Again the availability of water as a solvent facilitates these processes(6). Many of the products we use in the home are conveniently made in aqueous solutions; examples are bleaches, disinfectants, paints and some medicines.

The last sentence could be an alternative to the sixth point.

3 See Exercise 1 in Chapter 7 and its answer. Two marks for the description (in Exercise 1), 2 marks for identifying two sources of error and 2 for suggesting ways of minimising them.

4 See Sections 7.3 to 7.6. Two marks for comparisons and 2 for deductions about intermolecular forces.

Hydrogen sulfide has a higher molecular weight than water (34 compared with 18)$^{(1)}$ but it has much lower melting and boiling points than water: H_2S is a gas at room temperature while water is a liquid$^{(2)}$. Higher molecular weight compounds normally have higher melting and boiling points$^{(3)}$, so the reverse situation with water and H_2S tells us that there are much stronger intermolecular forces in water than in hydrogen sulfide$^{(4)}$. Melting and boiling points tell us nothing about intramolecular forces (chemical bonds).

The last sentence is not really necessary; it just makes sure of the marks. Note that the question does not ask you to discuss hydrogen bonding or dipole–dipole forces, so do not include them.

5 This is compulsory Experiment 1 on page 237. See also Exercise 4 in Chapter 7.

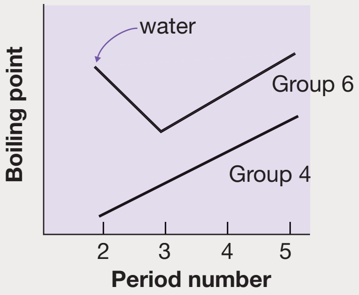
We dissolved measured masses of sodium chloride (or ethylene glycol) in separate 100 mL volumes of water in labelled conical flasks$^{(1)}$. We then gently boiled each solution with a thermometer immersed in it and recorded the boiling point once it had reached a stable value$^{(2)}$. We used the same thermometer for all measurements. Finally to check the accuracy of the thermometer we measured the boiling point of pure water$^{(3)}$. We prepared a table of concentration of salt (or ethylene glycol) with change in boiling point (the difference between that of the solution and that of pure water as determined by our thermometer).

Our results showed that the presence of a solute increased the boiling point$^{(4)}$ and that as the concentration of the solute increased, the boiling point increased$^{(5)}$.

Note the need to ‘measure’ the boiling point of pure water; thermometers often develop errors over time and could easily read, say, 100.8°C instead of the correct 100.0°C.

6 See Section 7.6. *Explain*, 1 mark; example (water or ammonia are the obvious ones), 1 mark; effect on properties, 2 marks. The obvious properties are melting and boiling points (taken as one property) and solubility in water; however, viscosity or surface tension would do.

7 See Section 7.6. Give the explanation around Figure 7.7 and include a rough sketch of that figure—the one below is sufficiently accurate for exam purposes; 3 marks for explanation, 1 for a diagram.



8 See Section 7.5. State what the importance is (1 mark), then assess it with some justification for your assessment (2 marks).

Molecular shape and bond polarity determine whether there will be any dipole–dipole forces between pairs of molecules. If there are dipole–dipole forces, then the intermolecular forces will be stronger than if there were no dipole–dipole forces; that is, if there were only dispersion forces; for example polar PCl_3 is a liquid while non-polar BCl_3 is a gas$^{(1)}$. Shape and polarity are quite important in determining the strength of intermolecular forces but they are not critical$^{(2)}$ (the assessment). If there is a large number of electrons in a molecule, dispersion forces can be quite strong and so intermolecular forces are quite strong regardless of whether there are any dipole–dipole forces. Non-polar iodine, a solid at room temperature, is an example (justification for the assessment)$^{(3)}$.

9 See Section 7.7, last sub-section. The explanation for (b) is more involved than for (a) so assume 2 marks for (a) and 3 for (b). For (a) give the explanation in the reference. For (b):

b The density of a liquid is affected by how vigorously the molecules of the liquid are moving; that is, by how much thermal energy they have. As temperature falls there is less motion of the molecules so they tend to pack together more closely and so the density of the liquid increases$^{(1)}$. However in water there is another factor coming into play; that is the ability of water to form hydrogen bonds with other water molecules as discussed in (a). As temperature (and so molecular motion) decreases, the amount of hydrogen bonding increases and as we saw in (a) this leads to a more open or lower density structure$^{(2)}$. So as water cools there are two factors involved: the slower motion of the molecules causes density to increase while the increased extent of hydrogen bonding causes density to decrease. These two conflicting tendencies mean that at some temperature density passes through a maximum: this occurs at 4°C$^{(3)}$.

10 This is compulsory Experiment 2 on page 237. See also Sections 7.2 and 7.7. The first three of the experiments described in *CCPC* BLM ‘measure’ surface tension (which is the result of the relative strengths of adhesion and cohesion; these two properties cannot be measured separately and are no longer part of the syllabus). The capillary attraction of the fourth experiment is also just a manifestation of surface tension. The fifth experiment measures viscosity. Describe the experiments you actually did; they may have been a selection of those experiments. The sample answer below uses different experiments. However, note that you need to compare results for water with those for other liquids. Glycerol (or perhaps ethylene glycol) and hexane (or perhaps acetone) are good choices for 'other liquids'. Two marks for the comparisons and 3 for the description.

To demonstrate the surface tension of water and to compare it qualitatively with that of other liquids (we used glycerol and hexane). We filled three shallow containers (Petri dishes or evaporating basins) with the liquids, then tried to float first a razor blade then a small metal paperclip on the surface of each liquid. Both the paperclip and the razor blade easily floated on glycerol. The razor blade easily floated on water, but only with difficulty could we float the paperclip on water. We could not float either the razor blade or the paperclip on hexane. Both of these items have densities greater than water so without surface tension they would not float. These experiments showed that glycerol had the greatest surface tension, water was next while hexane had the lowest surface tension.

To demonstrate viscosity we selected a filter funnel with a narrow outlet tube. With a finger over the outlet we poured 100 mL of each of the three liquids in turn into the funnel and measured the time for all the liquid to flow out of the tube after the finger was removed. Hexane took the shortest time, while glycerol took the longest. Since viscosity is a measure of the ease with which a liquid flows over a surface or through a tube, this experiment shows that water has a higher viscosity than hexane but a lower one than glycerol.

11 See Sections 7.9 and 7.11. Two marks for each substance. Sodium chloride breaks up into separate ions (because of the attraction of polar water molecules for ions), sucrose dissolves as separated molecules (because of the strong hydrogen bonding that can occur between the OH groups on sucrose and water). Iodine also dissolves as separated molecules, but in this case there are only weak dispersion forces between water and iodine molecules; because these forces are weak, the solubility of iodine is quite low in contrast to that of sucrose which is high. You do need to contrast the solubilities of sucrose and iodine to get both marks for iodine.

12 This is compulsory Experiment 3 on page 237. See also Section 7.13. Three marks for describing the experiment and 3 for the summary of results.

To test the solubility of each of the substances provided we put water to about a 3 cm depth in a test tube, then added a small amount of the solid (the amount that would fit on the tip of a small spatula). We stoppered the test tube, then shook it vigorously and noted first whether all of the solid had dissolved and, if it had not, whether it appeared that some of it had dissolved. If some of it seemed to have dissolved, we added extra water to the test tube and shook it again in order to decide whether the substance was soluble or not. In this way we tested sodium chloride (soluble), copper sulfate (soluble), calcium carbonate (insoluble), sucrose (soluble), naphthalene (insoluble), sand (silicon dioxide) (insoluble), starch (soluble after heating), some cotton threads (insoluble) and a piece of knitting wool (insoluble).

Our results could be summarised as follows:

Ionic substances are generally soluble (NaCl and $CuSO_4$), although some are insoluble ($CaCO_3$). Covalent molecular substances can be soluble if hydrogen bonding is possible (sucrose), but are generally insoluble (naphthalene). Covalent network solids are insoluble (silicon dioxide). Some large biological molecules are soluble (starch) while others are insoluble (cotton or cellulose and wool, a protein).

13 See Sections 8.2 and 8.3. *Evaluate* means make a judgement (1 mark), then give reasons for your judgement, by explaining how the table is useful and pointing out its limitation (2 marks).

A table of solubilities is very useful for deciding whether a precipitate will form or not, but it is not foolproof(1). If we mix a pair of solutions (such as zinc sulfate and sodium hydroxide), there are two possibilities for a precipitate (zinc hydroxide or sodium sulfate in the example). By checking a table of solubilities we could determine if either or both of these substances is insoluble and hence whether it would precipitate out (zinc hydroxide would but sodium sulfate would not). Hence a table of solubilities is useful(2). However if the concentrations of the mixed solutions are low, the table may predict that a precipitate would form, but none may appear, because the concentrations are too low. This can happen, for example, with lead chloride and silver sulfate(3).

14 See Section 8.6. Explain that dynamic equilibrium involves both the forward and reverse reaction occurring at equal rates (1 mark); use precipitation and dissolution as the example (1 mark). For demonstrating the dynamic nature, use the experiment involving the addition of radioactive lead nitrate to a saturated solution of lead nitrate (2 marks).

15 See Section 8.8. *Justify* … then *mention* …: there is no need to list the different measures separately—just make sure you mention four in your justification. *Justify* here means explain why and the best way to do this is to illustrate how different measures are most suitable to particular situations. Four marks, so there will be one mark for each measure along with why (or by whom) it is used. The four measures that are most easily justified are (i) mass or volume of solute per unit volume of solution (in commerce and industry for obtaining masses or volumes of substances that are provided as solutions), (ii) per cent composition (as for (i) but shorter to say and write), (iii) parts per million (environmentalists), (iv) molarity (chemists working with chemical reactions).

16 This is compulsory Experiment 4. See also Section 8.2. You may have performed this experiment using test tubes as described in *CCPC* BLM or you may have done it by mixing drops of solutions on a ceramic tile (semi-micro scale). Describe the actual experiment you performed. You should have used (and in your description named) the anions, chloride, sulfate and hydroxide (and possibly carbonate and/or acetate) and you probably used the cations, sodium, potassium, magnesium, calcium, barium, aluminium, silver, copper, zinc, iron and lead, though you would not be expected to list all the cations. A statement such as 'we tested about ten different cations' would suffice. However a sentence along the lines 'The cations were present in solution as nitrates, because all nitrates are soluble' is highly desirable—it explains why nitrate is not in your list of anions and summarises the solubility of nitrates. The table would have had anions as column headings and cations as row headings (or vice versa), with a note to write 'ppt' (for example) where a precipitate forms and a dash (for example) where no precipitate forms. (4 marks for describing the experiment, 1 mark each for two sources of error and how to avoid them.)

The main sources of error in this experiment would be (i) contaminating the solutions by dipping the wrong eye-droppers (Pasteur pipettes) into them (avoided by having all reagents in eye-dropper bottles and replacing the dropper immediately after use and before opening another bottle), (ii) confusing which solution was in which test tube (or on which location on the ceramic tile) (avoided by clearly labelling test tubes or locations on the tile) and (iii) not being careful enough in looking for a precipitate (often just some turbidity) after mixing solutions.

17 See Section 8.4. State your evaluation (1 mark), then give reasons for it (2 marks). Sometimes examiners may disagree with part of your evaluation—in this case disagree with 'but sometimes it can be superfluous'—but if you give an adequate explanation for your evaluation, in this case the sentence beginning with 'If the context …', then you will still get full marks. Had you omitted the 'but sometimes …' clause and the final sentence you would also have received full marks (2 marks for the two reasons for why it is useful). This emphasises that in *assess, evaluate, justify* questions there is not always just one right answer.

The inclusion of state symbols in chemical equations is generally very useful but sometimes it can be superfluous(1). It is useful first because it gives us a clearer picture of just how the reaction was carried out, whether in solution, as solids or as liquids, and secondly because it often identifies the 'drive' that made the reaction go, such as the formation of a gas or of a precipitate(2). However, on occasions it can be superfluous. If the context makes it clear that reactions are all being performed in aqueous solution, then adding (*aq*) to every formula can be tedious—just putting (*g*) or (*s*) on the relevant species can focus attention on the driving force for the reaction(3).

18 This is compulsory Experiment 5. See also Section 8.9. There are 5 marks for this question and there is no part about sources of error or suggestions for improvement, so you need to give full details of your procedure. Note that you have to name the pieces of apparatus used. The initial solution was made by accurately weighing out a mass of solid, then dissolving it in water and making the solution to an accurate volume in a volumetric flask. For dilutions you used a pipette and a volumetric flask, not measuring cylinders. For successive dilutions you could have done 25 mL (pipette) into 250 (volumetric flask) three times (final solution 10 × 10 × 10 = 1000 times more dilute than the starting solution) or 10 mL into 250 mL twice (total dilution 25 × 25 = 625) or even 25 mL into 500 mL, then 10 mL into 500 mL (total dilution 20 × 50 = 1000). 1 mL into 1000 mL would not satisfy successive dilutions and would not be particularly accurate (because of the accuracy of a 1 mL pipette).

19 See Section 8.14. *Outline*: describe briefly (4 marks); four of the six problems listed would suffice. *Assess their significance*: make some comment on how serious the problem is for the two situations and why (2 marks).

20 See Section 8.13. *Discuss* in this context means comment on how effective (1 mark), identify the factors that make it effective (1 mark) and explain how they do this (2 marks).

Water is a very effective heat transfer and temperature moderating agent in living organisms(1). This is because of its high specific heat capacity and its high thermal conductivity (compared with other liquids) and the fact that water makes up such a large proportion of any organism (60 to 90%)(2). Its high specific heat capacity means that when the surroundings heat up, the temperature of the organism, which is predominantly water, increases only slowly because comparatively it takes a lot of heat to raise the temperature of water through each degree Celsius. Similarly when the temperature of the surroundings falls, the high water content means that the organism's temperature falls much more slowly than that of the surroundings(3). For transferring heat away from or into cells the high heat capacity of water means that a small amount of water can carry a lot of heat and the high thermal conductivity means that this heat quickly flows out of or into the water(4).

Module 3 revision test

1 c **2** c **3** b **4** d **5** d
6 b **7** c **8** a **9** b **10** d

11 a 16.56 g **b** 15.4 mL

12 See Figure 7.1 for electron-dot structures.
Electron-dot structures are of limited value in predicting the physical properties of these substances. While telling us that these compounds are small covalent molecules (and therefore have low melting and boiling points and do not conduct electricity), electron-dot structures do not tell us anything about the polarity of the covalent bonds or the shape of the molecules and hence of the polarity of the molecules, and so give no information about intermolecular forces, which markedly influence physical properties such as melting and boiling points and solubility.

13 See Section 7.13. Assess the validity of the suggestion (1 mark), then explain why your assessment is correct; polarity is just one factor, the other being hydrogen bonding. Since there are 4 marks, you will need to include examples to support your argument.

The suggestion is not valid; polarity is just one factor in determining solubility but it is not the only one and not always the major one(1). For ionic compounds such as sodium chloride and copper sulfate, polarity of the water molecule is the most important factor in determining their solubility(2) but for covalent compounds the ability to form hydrogen bonds between solute and water molecules is by far the most important factor in determining solubility(3). For example glucose and other sugars readily dissolve in water because of the formation of hydrogen bonds, while smaller polar covalent molecules that cannot form hydrogen bonds are generally insoluble in water; for example ether and dichloromethane are quite polar molecules but are insoluble in water(4).

14 a sulfuric acid and barium bromide; magnesium chloride and sodium hydroxide (or copper nitrate and sodium hydroxide)

b one of **i** $Ba^{2+} + SO_4^{2-} \longrightarrow BaSO_4(s)$
ii $Mg^{2+} + 2OH^- \longrightarrow Mg(OH)_2(s)$ or
iii $Cu^{2+} + 2OH^- \longrightarrow Cu(OH)_2(s)$

c one of **i** $Ba^{2+} + 2Br^- + 2H^+ + SO_4^{2-} \longrightarrow BaSO_4(s) + 2H^+ + 2Br^-$
ii $Mg^{2+} + 2Cl^- + 2Na^+ + 2OH^- \longrightarrow Mg(OH)_2(s) + 2Na^+ + 2Cl^-$ or
iii $Cu^{2+} + 2NO_3^- + 2Na^+ + 2OH^- \longrightarrow Cu(OH)_2(s) + 2Na^+ + 2NO_3^-$

15 This is compulsory Experiment 6 from page 237. See also Section 8.14, particularly Example 13. A reasonable allocation of marks would be 2 for the description, 3 for the measurements made and method of calculation, and 2 for sources of error and how they were minimised. Make sure you treat all three aspects. Two of the three sources of error given below would suffice to get the 2 marks.

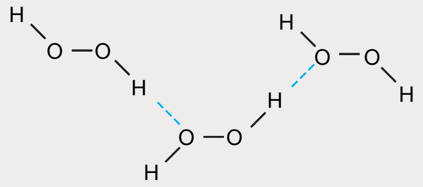
We put a measured mass of water in a polystyrene foam drink cup and a measured mass of solid in a beaker(1). After measuring the temperature of the water we added the solid to it, stirred it with the thermometer to dissolve it, then measured the highest or lowest temperature reached(2).

The quantities measured were mass of solid, mass of water and initial and final temperatures of the water(3). To calculate the heat of solution we first calculated the heat released or absorbed during the dissolution using total mass × specific heat capacity × change in temperature(4). We calculated the heat released or absorbed per gram by dividing by mass of solid, and finally heat per mole by multiplying by the molar mass of the solid. If heat was released (temperature rose), then ΔH_{soln} was minus this quantity; if temperature fell, ΔH_{soln} was positive(5).

The major sources of error were (i) loss of heat to the surroundings, (ii) ignoring the heat capacity of the container and thermometer and (iii) lack of accuracy of the thermometer for measuring the relatively small temperature change (less than 20°C). To minimise (i) we used a polystyrene cup instead of a beaker (because of its good heat insulating properties) and protected the experiment from draughts; for (ii) using a polystyrene cup of quite low mass and using the thermometer to stir instead of using a separate stirring rod minimised this error; for (iii) we used the most sensitive thermometer available and used a moderately large mass of solid to produce a fairly large temperature change (2 marks for treating any two of these sources of error).

16 a 6.0×10^{-5} mol/L
b i pipette
ii volumetric flask see Figure 8.3.

17 a



b i CF_4 **ii** H_2S or PCl_3

18 a i remain the same; the solubility of a substance is independent of the amount of solid in contact with the solution.
ii yes; there is a dynamic equilibrium between the solid and solutes in solution, so some $CaSO_4$ solid is going into solution while an equal amount is crystallising out: this

transfers some of the radioactivity to the solution.

b 0.011 mol/L

c Solubility is greater than 0.011 and less than 0.013 mol/L, because no precipitation occurs when concentration is 0.011 mol/L, but does occur when we attempt to make a 0.013 mol/L solution.

19 See Table 7.1. Two marks for giving the physical states in the four zones, 1 mark for giving the approximate percentage of water in each of the zones: percentages can be more approximate than in Table 7.1, for example >90% for the hydrosphere and <5% for the atmosphere would suffice.

Chapter 9

2 The Earth also radiates heat to outer space—the same amount of energy as it receives from the sun.

4 Because when we burn these substances (either in a flame or in our bodies), we react them with oxygen to form carbon dioxide and water and liberate energy. This is just the reverse of photosynthesis in which plants use sunlight to form carbohydrates:

$$6CO_2(g) + 5H_2O(l) + \textit{energy} \longrightarrow C_6H_{10}O_5(s)\ \text{(starch)} + 6O_2(g)$$

$$12CO_2(g) + 11H_2O(l) + \textit{energy} \longrightarrow C_{12}H_{22}O_{11}(s)\ \text{(sucrose)} + 12O_2(g)$$

(The reverse reactions for burning wood and sucrose are equally acceptable)

5 orange, 33.7%; blue, 23.6%; it is dissipated as heat

6 **a** $6CO_2(g) + 6H_2O(l) + \textit{energy} \longrightarrow C_6H_{12}O_6(aq)\ \text{(fructose)} + 6O_2(g)$

$C_6H_{12}O_6(aq)\ \text{(fructose)} + 6O_2(g) \longrightarrow 6CO_2(g) + 6H_2O(l)$; 2830 kJ/mol liberated

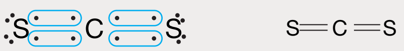
b $C_6H_{12}O_6(aq) \longrightarrow 2C_2H_5OH(aq) + 2CO_2(g)$

c It remains stored in the ethanol; yes, by burning or digesting this ethanol to carbon dioxide and water.

7 **a** In diamond all the atoms are close together, because they are all chemically bonded to one another. In graphite the atoms bonded to one another in the layers are close together, but the distance between layers is much larger than the bond length (see Figure 9.3). This gives graphite a lower density.

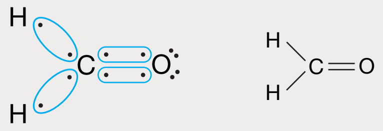
b graphite; buckminsterfullerene has a very open structure, because the atoms are on the surface of a sphere with much empty space inside.

8

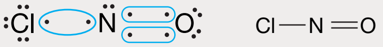


linear; because like ethyne which is linear C is bonded to only two atoms
non-polar, because C—S bonds are non-polar (C and S have similar electronegativities)

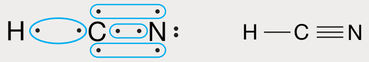
9 **a**



b



c



10 **a** formaldehyde, trigonal planar (same arrangement as around each C of ethene)
hydrogen cyanide, linear (same arrangement as around each C of ethyne)

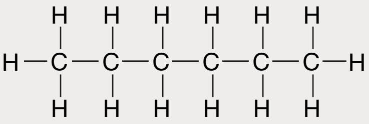
b all 3 are polar; the C—O bond in formaldehyde, the N—O bond in ClNO and the C—N bond in HCN are all polar and there is no cancelling out of identical bonds

11 **a** C_6H_{14} **c** C_7H_{16} **e** C_8H_{16} **g** C_8H_{10}
b C_8H_{18} **d** $C_{11}H_{24}$ **f** C_8H_{16} **h** $C_{10}H_8$

12 **a** C_9H_{20}, 128.3 **b** $C_{13}H_{28}$, 184.4
c $C_{24}H_{50}$, 338.7

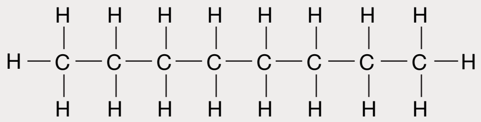
13 **a** pentane, C_5H_{12} **b** heptane, C_7H_{16}

14 **a**



C_6H_{14}

b

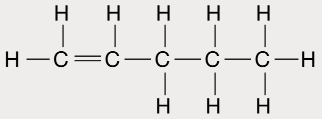


C_8H_{18}

15 C_2H_5; yes, C_4H_{10}; for structure see butane in Table 9.8

17 C_2H_4, C_3H_6, C_4H_8, C_5H_{10}, C_6H_{12}, C_7H_{14}, C_8H_{16}

18 **a**



b heptane: $CH_3{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}CH_3$
3-heptene: $CH_3{-}CH_2{-}CH{=}CH{-}CH_2{-}CH_2{-}CH_3$

19 **a** C_9H_{18} **b** $C_{13}H_{26}$ **c** $C_{18}H_{36}$

20 Yes; their molecular formulae C_4H_8 and C_6H_{12} can be represented by the same general formula C_nH_{2n}

21 **a** 3-hexene, 84.2 **b** 2-octene, 112.2

22 **a** $CH_3{-}CH{=}CH{-}CH_2{-}CH_2{-}CH_3$; 2-hexene (or $CH_2{=}CH{-}CH_2{-}CH_2{-}CH_2{-}CH_3$; 1-hexene)

b $CH_2{=}CH{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}CH_3$; 1-octene (or 3- or 4-octene)

23 **a** see 22(a)

b $CH_3{-}CH_2{-}CH{=}CH{-}CH_2{-}CH_2{-}CH_3$

24 **a** does not number C atoms from the end that gives the smaller number; 3-octene

b same error; 2-pentene

c number is not necessary because there is only one propene; propene

25 Isomers: b and c; e and g or e and f
Same compound: a and d; f and g

26 **a** and **d** 2-pentene **e** 3-hexene
b 1-butene **f** and **g** 2-hexene
c 2-butene

27 Boiling point of alkenes increases as number of C atoms in the molecule increases (as it did for alkanes). Boiling points of alkenes are slightly lower than those of the corresponding alkanes.

28 Straight-chain hydrocarbons include straight-chain alkenes and alkynes as well as straight-chain alkanes; for example $CH_3{-}CH{=}CH_2$ and $CH_3{-}C{\equiv}H$ are straight-chain hydrocarbons but not straight-chain alkanes: $CH_3{-}CH_2{-}CH_3$ is a straight-chain hydrocarbon *and* a straight-chain alkane.

29 gases: methane, ethane, propane, butane
petroleum ether: pentane, hexane
gasoline: heptane, octane

Chapter 10

1 exothermic: **a**, **c**, **d** endothermic: **b**, **e**
increase: **c**, **d** decrease: **e**

2 $NH_3(aq) + HCl(aq) \longrightarrow NH_4Cl(aq)$ exothermic
$K_2CO_3(aq) + NiSO_4(aq) \longrightarrow NiCO_3(s) + K_2SO_4(aq)$ endothermic

The fact that the test tube became warm in the $NH_3 + HCl$ reaction shows that the reaction must have liberated the heat that warmed up the test tube: if the reaction liberated heat, then by definition it is exothermic. In the second reaction the test tube got cold: that means that heat was taken away from the solutions, so the chemical reaction must have absorbed (taken in) heat: reactions that absorb heat are called endothermic.

3 **a** $2Mg(s) + O_2(g) \longrightarrow 2MgO(s)$
$\Delta H = -1.2 \times 10^3$ kJ/mol (for 1 mol O_2)
b $Zn(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$
$\Delta H = -154$ kJ/mol
c $MgCl_2(aq) + Na_2CO_3(aq) \longrightarrow$
$MgCO_3(s) + 2NaCl(aq)$ $\Delta H = +49$ kJ/mol

4 **a** 7.7 kJ released **b** 2.3 kJ absorbed
c 0.26 kJ released

5 $\Delta H = -57$ kJ/mol

6 –87 kJ/mol

7 **a** –99 kJ/mol
b +198 kJ/mol

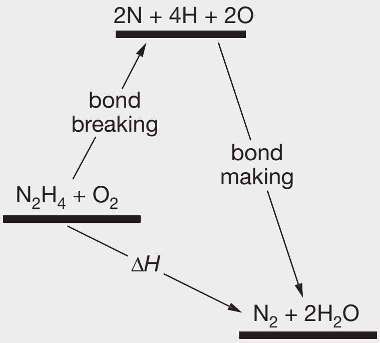
8 –4160 kJ/mol; should be like Figure 10.1(b)

9 **a** **i** 142.5 **iii** 50.0 **v** 16.5
ii 29.5 **iv** 50.3 **vi** 47.8 all in kJ/g
b hydrogen, propane, ethyne, octane, ethanol, sucrose; it's approximately the same; increasing oxygen content decreases the energy released per gram

10 **a** 33 MJ/L 25 MJ/L **b** 72 c/L

11 $N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$; need to break NN and HH bonds and make NH bonds; diagram should look like the left-hand one in Figure 10.2.

12 **a** $N_2H_4(g) + O_2(g) \longrightarrow N_2(g) + 2H_2O(l)$

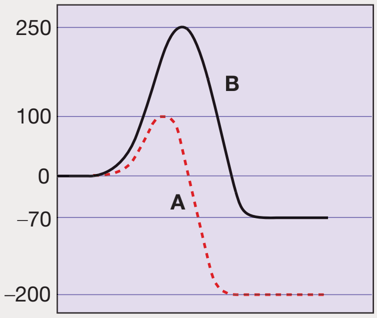


b –577 kJ/mol

13 **b** (i)

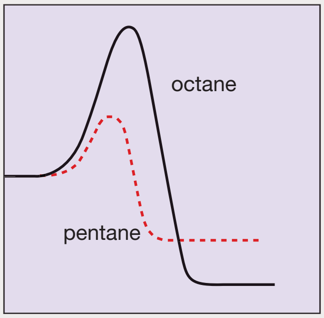
14 **a** $E_a = 40$ kJ/mol; $\Delta H = -30$ kJ/mol
b $E_a = 45$ kJ/mol; $\Delta H = +15$ kJ/mol

15



Fuel A would be the better fuel; fuel A would have the lower ignition temperature.

16



17 **a** $C_7H_{16}(l) + 11O_2(g) \longrightarrow 7CO_2(g) + 8H_2O(l)$
b $C_7H_{16}(l) + 9O_2(g) \longrightarrow 3CO_2(g) + 4CO(g) + 8H_2O(l)$
c $C_7H_{16}(l) + 8O_2(g) \longrightarrow CO_2(g) + 6CO(g) + 8H_2O(l)$
d $C_7H_{16}(l) + 7O_2(g) \longrightarrow C(s) + 6CO(g) + 8H_2O(l)$
e $C_7H_{16}(l) + 5O_2(g) \longrightarrow 5C(s) + 2CO(g) + 8H_2O(l)$
f $C_7H_{16}(l) + 4O_2(g) \longrightarrow 7C(s) + 8H_2O(l)$

As the ratio of oxygen to heptane decreases, the products contain less and less oxygen; that is, more CO and C formed and less CO_2.

18 2240 kJ/mol (assuming 8 molecules of CO formed per molecule of octane burnt); 41%

19 **b** experiment B, because the slope (gradient) of the curve is greater
c increasing the concentration of HCl increases the rate

20 0.28 mL s^{-1} for Expt A; 0.83 mL s^{-1} for Expt B

21 **a** *A*; it has the steeper slope

b *A*, because increasing reactant concentration generally increases the rate of a reaction

22 homogeneous: a, d, e heterogeneous: b, c, f

23 **a** greater in B; magnitude of the slope is greater

b B; reaction rate generally increases when temperature is increased

24 6 cm^2; 60 cm^2

25 **a** *A*

b *B*, because the rate increases more rapidly as temperature increases than in *A*

26 **a** endothermic: *C*; exothermic: *A*, *B*, *D*

b greatest *C*; least *D*

c greatest *C*; least *D*; the higher the activation energy the more rapidly does the reaction rate increase as temperature increases

28 Because we do not need to provide energy to maintain the temperature at 75°C.

30 Add a measured mass of manganese dioxide; then after the reaction is complete, filter it off, dry and weigh it. If it is a catalyst, then the mass recovered will be the same as the mass initially added (within experimental error), but if the manganese dioxide is a reactant in a separate reaction, the recovered mass will be significantly less than the starting mass.

Exam-style questions for Module 4

See explanatory notes under Exam-style questions for Module 1.

As in previous Exam-style answer sets superscripted numbers count the 'significant facts' (or marks) in each answer.

1 See Section 9.2. This question has two parts, *explain* and *evaluate*, and there are 5 marks: a reasonable assumption is that there are 3 marks for *explain* and 2 for *evaluate* so we need at least 3 significant facts for *explain* (4 to be safe) and at least 2 for *evaluate*. *Evaluate* means work out how important something is.

Photosynthesis is the process in which plants take carbon dioxide from the atmosphere and water from the soil and use their chlorophyll to absorb light energy from the sun(1) and make carbohydrates such as glucose, sucrose and starch(2). Some of the solar energy absorbed by the plant is stored in these carbohydrates as chemical energy(3)—it becomes available to us when those compounds undergo chemical reaction. An equation for photosynthesis is:

$$6CO_2(g) + 6H_2O(l) + \text{light} \longrightarrow C_6H_{12}O_6(aq)\ (\text{glucose}) + 6O_2(g)^{(4)}$$

Photosynthesis is extremely important for life on Earth—plants absorb their energy requirements directly by photosynthesis whereas animals and other life forms get their energy by eating plants (or other animals that ate plants)(1). Without photosynthesis there would be no life at all on Earth(2), so photosynthesis is essential for life on Earth.

2 See Sections 9.3 and 9.12. *Discuss* in the context of this question means work out how accurate or how generally true the statement is. Four marks means at least 4 significant facts (5 to be safe): what are fossil fuels, how were they formed, what does stored solar energy mean, hence how accurate is the statement?

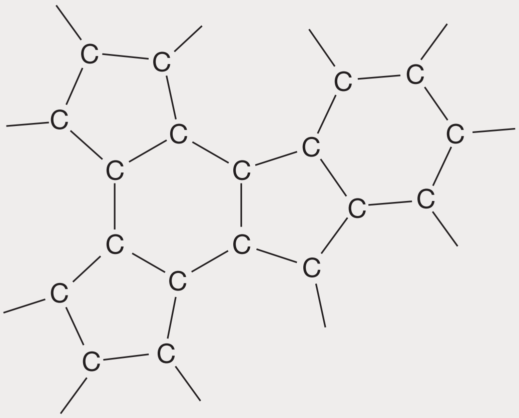
Fossil fuels are substances that were formed by the action of heat and pressure on decaying plant and animal matter over millions of years(1). The common fossil fuels are coal, oil and natural gas(2). Fossil fuels are considered stored solar energy, because the plant and animal material did not decay completely(3), so when these fuels are burnt (to form carbon dioxide and water) they release (as heat) the remaining energy that went into making the plants and animals(4). The energy released when fossil fuels burn came originally from plants, which collected it from sunlight, and so fossil fuels are accurately described as stored solar energy(5).

3 See Sections 9.6 and 9.7. Describe briefly (preferably with an electron-dot structure for each) what single, double and triple CC bonds are and give one example (structural formula, preferably with name of the compound) for each—there would be 1 mark for each description and 1 for each example.

4 Give the three reasons in Section 9.7, last sub-section; for good measure you could state why there are just as many compounds of hydrogen.

5 See Section 9.5. Probably 3 marks for structure and 1 for why they are allotropes. For the *explain* part you need to make clear that you know what allotropes are. While it is too difficult to draw a full soccer-ball structure, you should draw a partial structure to show you know what you are talking about.

Fullerenes consist of carbon atoms joined by covalent bonds and arranged into five- and six-membered rings that are joined to one another(1). The simplest is buckminsterfullerene, which has 60 C atoms per molecule with the rings arranged as on a soccer ball(2):



(3)

Each carbon atom is bonded to three other C atoms, with the fourth valence electron being present in a delocalised electron cloud(4).

Fullerenes are allotropes of carbon because they are pure carbon solids that have distinctly different physical properties from the other forms on solid carbon, namely diamond and graphite(5).

6 See Section 9.5. Give at least two uses for each (jewellery and cutting tools for diamond, electrodes, dry lubricants and lead pencils for graphite), 3 marks; properties: for diamond hardness, for graphite electrical conductivity and slipperiness, 2 marks.

7 See Sections 1.10 and 9.8. There are probably 2 or 3 marks for the explanation and 3 or 2 for the *outline its use* so you should work on the basis of 3 marks for each—3 significant bits of information for each. A diagram is highly desirable.

Fractional distillation is a process for separating liquid mixtures. The mixture is heated to produce vapour, which is then repeatedly condensed and re-vaporised(1). Each time the liquid vaporises, the vapour becomes richer in the more volatile component(2). If enough condensations and re-vaporisations are done, a pure sample of the most volatile component emerges from the top of the fractionating column(3).

In refining crude oil, fractional distillation is used to separate the mixture into about five or six fractions (mixtures), not to separate it into pure compounds(4). A series of trays and bubbler caps is used.

Draw a diagram(5) similar to Figure 9.7 but omit the vacuum distillation and solvent extraction bits. Show the fractions that are formed, namely non-volatile greases and waxes, heating oil and diesel fuel, kerosene, petrol, petroleum ether, LPG(6), and indicate the order of increasing volatility (decreasing volatility)(7). The numbers of C atoms are not necessary.

8 Describe the experiment you actually performed but do not overlook the last sentence—there will be at least 1 mark for this, possibly 2. If you did the experiment in *CCPC* BLM page 170, emphasise that each distillation was a single-step distillation, not a fractional distillation. Explain that several successive distillations are needed to illustrate fractional distillation. The experiment would be more effective at illustrating fractional distillation if you did several (say, three or four) successive distillations, perhaps starting with a larger volume of 50:50 mixture (say, 200 mL) and collecting 80, 40, 20, 10 mL of distillate. Another way of making the experiment more effective would be to use a laboratory fractionating column (Figure 1.6).

If your school had a fractionating column available, then the ideal experiment would have been to use it to distil a 50:50 mixture of ethanol and water and measure the concentration of the distillate obtained (using density), and then to use a simple distillation apparatus (Figure 1.5) to distil a similar mixture and compare the concentrations of the two distillates. In this case the way to improve the experiment would be to use two fractionating columns of different lengths and compare their distillates.

9 See Sections 9.9 and 9.10. Describe the intermolecular forces in these compounds, then explain how they give rise to relevant physical properties—low melting and boiling points, low densities, insolubility in water. Other physical properties such as being non-conductors of electricity do not arise from intermolecular forces and so are not relevant to the question. Five of the 7 points below would get you full marks.

Alkanes and alkenes are non-polar molecules(1), because CC bonds are non-polar and while CH bonds are slightly polar the large amount of symmetry in the molecules cancels out most of this small amount of polarity(2). This means that the only intermolecular forces are dispersion forces(3). These are relatively weak, which means that it is relatively easy to separate molecules from one another and so these compounds have low melting and boiling points(4). Dispersion forces become stronger as molecular weight increases (as number of electrons in the molecule increases), and so melting and boiling points increase as molecular weight increases(5). Weak intermolecular forces mean that molecules are not held to one another very firmly and so the compounds have low densities(6). The non-polar nature of the molecules means that they do not dissolve in highly polar water(7).

10 See Section 9.9, second sub-section. *Discuss* requires some consideration of advantages and disadvantages. You must include at least one of each. The first three points below would get full marks. (4) would do instead of (3); (5) is not really necessary.

IUPAC nomenclature or systematic naming is useful because the name allows us to work out the structure of the compound from the name or to work out the name from the structure(1). This means chemists no longer have to memorise long lists of names for structures(2). One disadvantage of systematic naming is that it was introduced long after many common (or so-called trivial) names (such as acetic acid and acetone) had become entrenched in chemical industry, and many chemists refused to adopt the new names(3). Another disadvantage is that IUPAC names are often longer and more complicated than the old names(4). An added advantage is that each compound has only one correct systematic name; this can minimise the confusion that can arise when one compound has more than one trivial name, as is common with pharmaceuticals(5).

11 See Section 9.11. You first need to explain what the concept of functional groups is, then make comments about how useful it is, with probably 2 marks for each part.

The concept of functional groups is that a molecule is made up of a centre of reactivity (functional group) and a relatively unreactive alkane fragment or chain (alkyl group)(1). The functional group determines what reactions the molecule undergoes(2). This concept is extremely useful because it means that we can study the chemistry of large sets of compounds (such as alkenes or alkanols) instead of having to study the reactions of long lists of individual compounds(3). It makes it easy to generalise about the reactions of large numbers of compounds that contain the same functional group(4).

12 See Section 9.14. You need to state three safety precautions, then decide how effective each one is. One mark for each precaution and 1 for its assessment. Note that the question concerns only liquid alkanes, not gaseous ones. Good safety precautions to discuss with their effectiveness in brackets are (i) use sturdy containers with narrow mouths (very effective because the container is unlikely to rupture if a fire occurs and the narrow mouth limits leakage and spillage), (ii) minimise the quantities in everyday use (very effective because it limits the possible damage that could occur if there is a fire and makes the fire easier to put out), (iii) keep them away from naked flames, sparks and electrical equipment likely to create sparks (very effective because it limits the possibility of alkanes being ignited), (iv) store bulk quantities in well-ventilated places (effective only if the ventilated places are securely fenced and located well away from passing traffic) and (v) erect warning signs prohibiting cigarette smoking, naked flames and electrical equipment (only effective if it is tightly policed because people often ignore warning signs).

13 See Section 9.14. Explain why you would adopt four particular safety procedures. One mark for each explanation. Perhaps three would do, but it would be safer to break them into four. Any four of the following would suffice.

(i) Store gaseous alkanes such as methane, ethane and propane (LPG) in strong cylinders so that if they fall over or are hit they will not rupture and let flammable gas escape. (ii) Carefully leak-test all fittings and pipe work used to carry the gases from their storage cylinders to the appliance using the gas, because these gases are extremely flammable and if there was a leak an explosive mixture of gas and air would quickly build up. (iii) Dose the gases with small amounts of nasty smelling substances so if a leak does develop it would be quickly detected (gaseous alkanes are odourless). (iv) Store the cylinders containing these gases outside of the buildings or vehicles they are being used in so that if there is a major leak or cylinder rupture it will not be into a confined space where an explosive mixture with air would swiftly build up.

14 See Section 10.5 (and 10.2 for definition of enthalpy change). Explain what enthalpy change means (energy absorbed) (1 mark), explain that breaking bonds requires energy to be absorbed by the molecules and that making bonds releases energy (1 mark) and state how enthalpy change is related to these two quantities (1 mark).

15 See Sections 10.6 and 10.7. *Account for* is another way of saying *explain*. The key points are (i) there is an activation energy, (ii) if it is high there will be negligible reaction at room temperature, (iii) we need to heat the mixture to get reaction started, and (iv) if the reaction is exothermic, then once we get it started it becomes self-sustaining.

This is because reactant molecules must possess a certain minimum amount of energy, called the activation energy, before they can react to form product molecules(1). If the activation energy is relatively high, then at room temperature virtually none of the reactant molecules has this amount of energy and so no reaction occurs(2). If we heat the reactants until some of them have this minimum amount of energy, then reaction will occur(3). If the reaction is exothermic, then it will release energy as heat and this will be able to keep the reactants at a sufficiently high temperature for the reaction to keep occurring(4).

16 See Section 10.8. Because of *evaluate* you need not only to list the procedures but also to make some comment on how effective or efficient they are. Because of 7 marks you need at least seven significant bits of information in your answer. To organise your thoughts before you start writing your actual answer, it might be best to list the four common types of pollution, then recall how of each of them is addressed. If you can't think of seven methods, then give extra information about a couple of the ones you can list. But be careful—this is a question where you could easily write too much information for 7 marks and if you don't keep *evaluate* in mind you might not get full marks anyway!

The common forms of pollution are (i) CO and soot (C) from incomplete combustion, (ii) oxides of nitrogen from $N_2 + O_2$ at high temperatures, (iii) sulfur dioxide from sulfur compounds in fuels, and (iv) particulates, mainly soot and non-combustible inorganic substances in coal. The procedures to minimise these, with their evaluations after the dash, are: for (i) use excess air (in diesel engines and power stations)—very effective, crush coal into very fine particles—reasonably effective, and use catalytic exhausts (in petrol engines)—very effective if engines are well maintained; for (ii) use catalysts to convert NO and NO_2 to N_2 (in vehicles and more recently in some power stations)—very effective, locate power stations away from population centres—only partially effective because it does not actually eliminate the pollutant; for (iii) remove sulfur compounds from fuels—very effective for oil-based fuels and natural gas, only partially effective for coal (too difficult), use low sulfur coals—again of limited effect; for (iv) use electrostatic precipitators (for power stations)—very effective.

17 See Section 10.10. *Demonstrate* here means 'give examples that show'. Assume 1 mark for each of the three examples and 1 mark for the conditions that favour each.

18 See Section 10.12. You need to describe the experiments that you actually performed and you cannot pay too much attention to the 1 mark per important fact rule here—just give the necessary information as briefly as possible. There are four reaction variables that could be used—the three at the start of the sample answer below plus the state of division (or surface area) of a solid. Choose any three. If you did the experiments in *CC* BLM you would have used the reaction between thiosulfate and acid (to form sulfur and sulfur dioxide) for concentration and temperature, decomposition of hydrogen peroxide with and without manganese dioxide for catalyst, and reaction between magnesium and hydrochloric acid for surface area. Other reactions are also widely used for this experiment. The answer below uses a reaction not widely used but it should give you an idea of how to answer such a question. For 6 marks you do not have time to give too much detail but you do need to convince the examiner that you actually did the experiment. Note that the experiment is described briefly (*outlined*) as required and the results are summarised at the end, as also was required.

The three reaction variables that we investigated were (i) concentration of a reactant, (ii) temperature and (iii) presence of a catalyst. We used the reaction between aqueous hydrogen peroxide and acidified potassium iodide solution (both colourless). These react to form a brown solution of iodine:

$$H_2O_2(aq) + 2I^-(aq) + 2H^+(aq) \longrightarrow I_2(aq) + 2H_2O(l)$$

We had the two solutions in separate beakers and started the reaction by mixing them. However, before doing this we prepared a separate reference solution containing an iodine concentration that corresponded to reaction of about 20% of the hydrogen peroxide to be used in the rate measurement experiments; in our actual experiments we measured the time required for the mixed solution to develop the same colour intensity as the reference solution. The shorter the time, the greater the rate of reaction. We did four experiments:

1 base experiment at room temperature
2 double the concentration of iodide at room temperature
3 same concentrations as in 1 but at 35°C
4 same concentrations as in 1, again at room temperature, but with a small amount of sodium molybdate solution added as a catalyst.

Comparison of experiments 1 and 2 showed that increasing a reactant concentration increased the rate of reaction. Comparison of 1 and 3 showed that increasing the temperature increased the rate. Comparison of 1 and 4 showed that the presence of a catalyst increased the rate.

19 See Section 10.13 and the start of 10.14. *Identify* in this question means *name* or *list*. The factors are concentration, surface area, rate of stirring, temperature (4 marks). Note that you are not asked to explain how each of these factors increases the rate of collision, but rather how increasing the rate of collision increases the rate of reaction—for reaction to occur reactant particles must collide, so increasing the rate of collision will increase the rate of reaction (1 mark).

20 See Section 10.16. Give two methods (minimising the production of small particles or of their escape into the air, and ventilating the air space very thoroughly) (2 marks), *and* comment on how effective they are or which is more effective (stopping their formation or escape into the air) (2 marks).

Module 4 revision test

1 c **2** b **3** b **4** d **5** c
6 c **7** a **8** c **9** d **10** d

11 **a** $CH_2=CH-CH_2-CH_2-CH_2-CH_3$ (or $CH_3-CH_2-CH=CH-CH_2-CH_3$)
b $CH_2=CH-CH_3$ (or butene or pentene)
c $CH_3-CH_2-CH_2-CH_2-CH_2-CH_3$; hexane

12 **a** The same mass of H_2O_2 has decomposed, so there has been the same mass of oxygen lost in both experiments.
b The rate in experiment *B* is faster. This is because manganese dioxide is a catalyst: using more catalyst makes the reaction go faster.

13 See Sections 9.4 and 9.5. *Compare*—point out similarities (network solid, covalent bonds) (1 mark); *contrast*—point out differences (diamond three dimensional, graphite, planar layers) (1 mark); draw structures (1 mark). Explain any three of the following (1 mark each): high melting and boiling points (network solids), hardness of diamond (3D structure), softness of graphite (planar layers can slide), electrical conductivity (none for diamond because all valence electrons are tied up in covalent bonds, some for graphite because it has some delocalised electrons).

14 **a** because when we react it with O_2 (either by our body's metabolism or by burning it), energy is released
b from sunlight by photosynthesis in plants:
$6CO_2(g) + 6H_2O(l) + \textit{energy} \longrightarrow C_6H_{12}O_6(aq) + 6O_2(g)$

15 see Sections 1.9 and 9.8, particularly Table 9.5

16 **a** $C_4H_{10}(g) + 6\frac{1}{2}O_2(g) \longrightarrow 4CO_2(g) + 5H_2O(g)$
or $2C_4H_{10}(g) + 13O_2(g) \longrightarrow 8CO_2(g) + 10H_2O(g)$
b 55°C

17 **a** and **b** see Sections 10.8 and 10.9

18 This is compulsory Experiment 4 on page 308. Also see Section 10.1. Assuming 1 mark each for the equations leaves only 3 marks for the description of the experiment so keep it brief, but try to include some detail to convince the examiner that you actually did the experiment (in the sample below stirring with the thermometer and noting the highest or lowest temperatures reached). Reactions commonly used in this type of experiment (other than those below) include Mg + HCl solution, steel wool + $CuSO_4$ solution, $AgNO_3$ + NaCl solutions (all exothermic) and hydrated barium hydroxide + ammonium thiocyanate solids (very endothermic but the equation is difficult to write!). Do not use reactions such as Mg + O_2 (cannot measure the temperature rise) or decomposition of $CaCO_3$ or of $Cu(NO_3)_2$ (have to heat them and so cannot measure the temperature fall). Using impractical reactions reveals that you did not perform the experiment.

For each reaction studied we put the reactants (either two solutions or a solid and a solution) into separate beakers and measured the temperature of the solution(s)(1). We then mixed the two reactants and stirred with the thermometer and noted the highest or lowest temperature that the mixture reached(2). If the temperature increased, the reaction was exothermic and if it decreased the reaction was endothermic(3). We did this for three (or four?) reactions. Two of the reactions we studied were:

(i) sodium hydroxide solution and sulfuric acid solution (exothermic)

$$2NaOH(aq) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)^{(3)}$$

(ii) reaction between magnesium chloride and sodium carbonate solutions (endothermic):

$$MgCl_2(aq) + Na_2CO_3(aq) \longrightarrow MgCO_3(s) + 2NaCl(aq)^{(4)}$$

19 **a** See Section 10.14. *Interpret* in this context means *explain why* the rate rises rapidly. Three marks mean you need to give a fair amount of detail, probably three significant bits of information.

Reactant molecules need to have a certain minimum amount of energy to react (the activation energy)(1). At low temperatures only a small fraction of the molecules has this—as temperature rises, the fraction increases very rapidly(2). Include a diagram like Figure 10.7 to show this(3). Hence reaction rate increases very rapidly as temperature increases.

Note: Although the rate of collisions between reactant particles increases as temperature rises, this is only a small effect and does not explain the rapid rate increase.

b See Section 10.15. 2 marks so two bits of information; the first sentence alone (below) would not justify 2 marks. However, 2 marks hardly warrants giving a specific example. To be safe you could add a diagram such as Figure 10.9.

Catalysts increase the rate of a reaction by providing a pathway for the reaction that has a lower activation energy that the uncatalysed reaction(1). Lowering the activation energy means that at any particular temperature the rate of the reaction increases(2).

Appendix

1 **a** 4 **c** 3 **e** 4
b 3 **d** 4 **f** 6
g not determinable from the way the value is written

2 **a** 19.23 **d** 0.006198
b 0.992 **e** 27.699
c 5.13×10^5 **f** 1.7×10^4

3 **a** 1.1×10^2
b 35
c 39
d 27.6
e 6.2×10^6
f 8.28×10^{-4}
g 1.16×10^6
h 9.85×10^7 (9.84×10^7 is equally correct)
i 1.449×10^{-2}
j 9.37×10^5 (2.46×5233.6 is 1.29×10^4; it does not matter whether 680 is 0.068×10^4 or 0.0680×10^4, the subtraction in the top line gives 1.22×10^4)